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**Survival, space use, and radio telemetry accuracy of white-tailed deer fawns in
central Iowa**

by

Patrick George McGovern

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Wildlife Ecology

Program of Study Committee:

Julie A. Blanchong, Co-Major Professor

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2018

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ABSTRACT

White-tailed deer (*Odocoileus virginianus*) are one of the most managed species in North America. Overabundant deer populations negatively affect vegetation communities, cause crop damage, and increase the risk of deer-vehicle collisions. To identify areas of management need and set accurate harvest quotas, managers need reliable estimates of deer population trends. Fawns suffer the highest rate of mortality of any age class, and it varies across their range in response to differences in landscape composition, predator community, and deer density. We radio-collared 48 fawns from 2015-2017 to document cause-specific mortality, estimate survival, and describe space use in central Iowa. Disease was the primary cause of mortality, followed by suspected predation and harvest. The estimated fawn survival rate was 0.78 through 30 days post-capture, 0.69 through 60 days post-capture, and 0.31 through 7 months post-capture. Declines in fawn survival through 7 months post-capture were the result of disease and harvest. Fawn home ranges were primarily comprised of woodland (>60%) and female fawns avoided agriculture. The proportion of nearby woodland had a positive effect on fawn survival. We used radio telemetry to estimate fawn locations and assess habitat selection. Locations derived from radio telemetry have inherent error that can bias habitat selection studies. We conducted trials to evaluate the effects of slope, observer experience, and fawn behavior on location accuracy. Location error varied among sites along a slope ($P < 0.001$); however, distance between sites and observer, not slope position, was the best explanation for differences in error. Location error did not differ between experienced and inexperienced observers ($P > 0.05$). Location error did not increase over time for radio-collared fawns ($\beta = 0.005$, 95% CI was -0.001, 0.010).

Confidence ellipse area was an indicator of location error ($\beta = 0.87$, 95% CI was 0.57, 1.18), which suggests it is an adequate proxy for accuracy of location estimates. Our finding of higher fawn survival in woodland habitat suggests that managers should maintain woodland habitat in agricultural regions. Disease caused most of our fawn mortality in contrast to predation as reported in other Midwestern studies. Our survival estimates through 30 and 60 days post-capture were similar to estimates from other Midwestern regions; however, survival through 7 months was much lower.

GENERAL INTRODUCTION

Background

White-tailed deer (*Odocoileus virginianus*) are one of the most studied and actively managed large game species in North America. The hunting of deer generated more than \$5 billion in state and federal taxes in the United States in 2011 (Southwick Associates 2012). In Iowa, white-tailed deer hunting generated \$196 million in retail sales and \$21 million in state and local tax revenue (Southwick Associates 2012). Deer were nearly extirpated from Iowa in the late 19th Century and the population reestablished in the 1930s, reaching peak numbers in 2006 (Harms 2017). The Iowa Department of Natural Resources aims to maintain the deer population at levels seen in the mid-1990s (~200,000 individuals in winter) through harvest (Harms 2017). In order to inform future harvest quotas and deer management plans, it is important to have contemporary estimates of the factors affecting Iowa white-tailed deer population trends.

Variation in survival, reproduction, emigration, and immigration all affect population trends. Deer fawns suffer the highest rates of mortality of any age class (Porath 1980). Typical sources of fawn mortality include predation, starvation, collisions with vehicles, and harvest (Bartush and Lewis 1981, Brinkman et al. 2004, Pusateri Burroughs et al. 2006). Predation is often the primary cause of fawn mortality (Bartush and Lewis 1981, Ballard et al. 1999), but habitat characteristics such as forest cover or understory vegetation density can reduce fawn predation rates (Rohm et al. 2007, Piccolo et al. 2010). Fawn survival is highly variable across the deer's range, but studies in the Midwest have generally reported high survival estimates for the region (Brinkman et al. 2004, Pusateri Burroughs et al. 2006). Fawn survival has been a focus of recent research in some Midwestern states (e.g., Piccolo et

al. 2010, Grovenburg et al. 2011, Warbington et al. 2017), but there have been no recent studies from Iowa (Huegel et al. 1985). Changes in deer population numbers, management priorities, and land use in the intervening years require contemporary estimates of fawn survival in Iowa. Fawn mortality can be difficult to detect through traditional survey methods. Fawns are “hidlers” early in life and spend most of their time concealed by vegetation (Lent 1974). They are small and their remains are quickly consumed by predators or scavengers, which makes discovering mortalities or determining the cause difficult (Bartush and Lewis 1981, Ballard et al. 1999). The most common way to estimate fawn survival is through intensive monitoring using radio telemetry (e.g., Bartush and Lewis 1981, Huegel et al. 1985, Pusateri Burroughs et al. 2006). Radio telemetry allows researchers to continually monitor the status of marked individuals and locate them as needed. Estimating locations of radio-tagged animals through triangulation can be useful in estimating movement rates or space use in a time- or energy-efficient way. However, estimated locations have inherent error (Heezen and Tester 1967). Topography, habitat, animal behavior, and the distance between a transmitter and receiver can all affect the accuracy of estimated locations (Ellis 1964, Slade et al. 1965, Garrott et al. 1986, Grovenburg et al. 2013). Increased location error can bias studies of habitat selection or movement (Heezen and Tester 1967, Nams 1989, Kauhala and Tiilikainen 2002). Understanding the effects of these factors on location estimates is important for drawing accurate conclusions from radio telemetry data.

Goals and Objectives

The goals of this study are to provide estimates of white-tailed deer fawn survival, identify causes of mortality, and describe fawn space use in central Iowa for use in

management decisions. To verify the accuracy of our space use data, we also aim to evaluate study-specific factors affecting the accuracy of triangulation locations. Our objectives are to:

1. Document cause specific mortality, assess space use and habitat selection, and estimate survival of white-tailed deer fawns in central Iowa (Chapter 1).
2. Evaluate the impacts of slopes, fawn behavioral stage, observer experience, and experience gain on accuracy of radio telemetry estimates (Chapter 2).

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CHAPTER 1. SURVIVAL AND SPACE USE OF WHITE-TAILED DEER FAWNS IN CENTRAL IOWA

Abstract

Survival rate estimation receives considerable attention from researchers interested in population trends. Survival can vary by region, sex, age-class, and habitat. White-tailed deer fawn survival and causes of mortality are highly variable across their range. While recent studies have documented fawn survival in several Midwestern states, there have been no published estimates of fawn survival in Iowa for 30 years. We radio-collared 48 fawns in central Iowa to determine cause-specific mortality, assess space use, and estimate survival. We recorded 21 mortalities, which were attributed to disease ($n = 9$), suspected predation (4), harvest (3), vehicle collision (1), starvation (1), and unknown (3). An outbreak of epizootic hemorrhagic disease (EHD) in 2016 caused 55% of total disease mortalities. Estimated fawn survival was 0.78 (standard error = 0.07) through 30 days post-capture, 0.69 (0.08) through 60 days post-capture, and 0.31 (0.02) through 7 months post-capture. Fawn 95% kernel density home ranges averaged 21.22 (2.74) ha at 30 days, 25.47 (2.87) ha at 60 days, and 30.59 (2.37) ha at 7 months. Female fawns avoided agricultural habitat within their home ranges. The proportion of nearby woodland had a significant positive effect on fawn survival through 30 and 60 days post-capture. Our 30- and 60-day survival estimates were comparable to previously reported rates for Iowa and the Midwest; however, our 7-month estimate was much lower. Outbreaks of sporadic diseases like EHD can cause significant late-season fawn mortality but did not reduce fawn survival compared to years without EHD mortality in our study. Our findings that woodland habitat was positively associated with survival suggests that maintaining or restoring woodland habitat in areas of limited or temporary cover such as the agricultural Midwest is important.

Keywords: fawn, habitat selection, home range, Iowa, *Odocoileus virginianus*, space use, survival, white-tailed deer

Population trends are the result of variation in survival, reproduction, immigration, and emigration rates. While reproduction, immigration, and emigration are important for understanding changes in populations, survival typically receives the most attention from researchers (Murray and Patterson 2006). Survival rates can be estimated for individuals grouped by factors such as region (McNew et al. 2012), sex (Shackell et al. 1994), or age-class (Kenward et al. 1999). Differences in age-specific survival can be the result of variation in predation risk, foraging efficiency, or disease susceptibility (DelGiudice et al. 2002, 2006). Landscape composition and habitat selection also affect survival by further altering predation risk and foraging efficiency (Laundré et al. 2001, Whittingham and Evans 2004, De Knecht et al. 2007). While adult survival is generally constant, juvenile survival can be highly variable in response to environmental stochasticity (Gaillard et al. 1998, Owen-Smith et al. 2005).

Neonatal ungulates have the lowest survival rates of any age class. They are more susceptible than adults to natural sources of mortality including predation, disease, and malnutrition in part due to their limited mobility, underdeveloped immune systems, and dependence upon their mother for nutrition (Porath 1980, Gaillard et al. 1998, DelGiudice et al. 2006). A combination of regional, behavioral, and intrinsic factors results in variable survival rates in neonate ungulates. Regional variation in survival occurs due to differences in climate (DelGiudice et al. 2002, Carstensen et al. 2009), predator community (Vreeland et al. 2004, Warbington et al. 2017), population density (Ozoga et al. 1982), and landscape composition (Rohm et al. 2007, Grovenburg et al. 2012a). Severe winters at northern

latitudes can reduce annual survival (Ballard et al. 1981, Carstensen et al. 2009). High population densities can increase neonatal mortality through competition for suitable fawning territory and by altering maternal behavior (Ozoga et al. 1982). High densities of predator species result in increased rates of predation and reduced neonate survival (Warbington et al. 2017). How individuals within a population utilize the landscape may affect their survival by altering exposure to particular sources of mortality (Hasapes and Comer 2017, Lendrum et al. 2018). High concentration of available resources results in small home range sizes, which in turn means individuals move shorter distances or less often (Ebersole 1980). Increased movement distance and frequency can increase exposure to predators (Jackson et al. 1972, Schwede et al. 1994). Selection for areas of hiding cover may decrease predation risk among neonates that rely on concealment while avoidance of roads will reduce the risk of collision with vehicles (Etter et al. 2002, Brinkman et al. 2004a, Piccolo et al. 2010). Consideration of site- and individual-specific factors affecting neonate mortality is important for managing ungulate populations.

As with other ungulates, neonatal white-tailed deer (*Odocoileus virginianus*) suffer higher rates of mortality than yearlings or adults (Porath 1980). Fawn summer survival estimates are highly variable across studies, ranging from as low as 0.10 in Oklahoma to a high of 0.91 in Michigan (Bartush and Lewis 1981, Pusateri Burroughs et al. 2006). The primary sources of fawn mortality include predation (Bartush and Lewis 1981, Ballard et al. 1999, Vreeland et al. 2004), starvation (Hiller et al. 2008), vehicle collision, and harvest (Brinkman et al. 2004a, Pusateri Burroughs et al. 2006). Predation accounts for the majority of fawn mortality in most studies (Bartush and Lewis 1981, Rohm et al. 2007, Grovenburg et al. 2011). Predators of fawns differ across their range, but include coyotes (*Canis latrans*),

domestic dogs (*Canis familiaris*), gray wolves (*Canis lupus*), black bears (*Ursus americanus*), and bobcats (*Lynx rufus*) (Huegel et al. 1985a, Kunkel and Mech 1994, Vreeland et al. 2004, Carstensen et al. 2009).

As a strategy to avoid predators, fawns are “hidiers” from birth until 4-6 weeks of age (Lent 1974). “Hidiers” are mostly sedentary and rely on visual concealment and cryptic coloration to avoid detection by predators. Most fawn mortality from predation occurs during this “hider” stage (Vreeland et al. 2004). Access to dense vegetative cover may reduce fawn predation risk during the “hider” stage, thereby increasing survival. Piccolo et al. (2010) found that predation rates were higher and fawn survival was significantly lower at sites with low vegetation density and vertical height than at sites with more cover. Fawns selected for conifers and deciduous forest over agricultural and open land in Michigan, which likely contributed to low rates of predation and a survival estimate of 0.81 through 2 months of age (Hiller et al. 2008). Rohm et al. (2007) and Gulsby et al. (2017) reported significant positive relationships between landscape heterogeneity and fawn survival in southern Illinois and South Carolina, respectively, whereas Vreeland et al. (2004) found no significant relationship between land cover type and fawn survival in Pennsylvania.

Fawn survival in Midwestern states is generally greater than in other portions of the deer’s range, with summer estimates of 0.84 in Minnesota (Brinkman et al. 2004a), 0.86 in Iowa (Huegel et al. 1985a), and 0.81 to 0.91 in Michigan (Pusateri Burroughs et al. 2006, Hiller et al. 2008). Previous studies have attributed high fawn survival in the Midwest in part to the agricultural landscape of the region. Agriculture provides ample food resources for adult deer, likely increasing their condition during winter and gestation (Brinkman et al. 2004a). The condition of does may have knock-on effects to fawn survival by increasing

birth mass or reducing abandonment rates (Verme 1977). Fawn body size and birth mass positively correlate with survival estimates (Carstensen et al. 2009). Additionally, high fawn survival estimates are generally correlated with lower predator densities. Midwestern states lack the diverse communities and high densities of predators of forested regions in the northern or eastern United States (Kunkel and Mech 1994, Vreeland et al. 2004, Warbington et al. 2017).

While fawn survival has been an area of focus in recent years in Midwestern states (e.g., Hiller et al. 2008, Piccolo et al. 2010, Grovenburg et al. 2011, Warbington et al. 2017), there have been no published studies of fawn survival in Iowa for several decades (Huegel et al. 1985a). In the years since Huegel et al., the Iowa deer population has peaked and management strategies have shifted from promoting growth to maintaining steady herd numbers through harvest (Harms 2017). Deer hunting in Iowa generated >\$210 million in retail sales and tax revenue in 2011 and the Iowa Department of Natural Resources aims to sustain an annual harvest of ~100,000 deer (Southwick Associates 2012, Harms 2017). Contemporary estimates of fawn survival are necessary to understand population trends and evaluate harvest impacts (Porath 1980). We studied fawn survival and space use in central Iowa to provide updated survival estimates for use in management decisions. Our study objectives were to 1) document cause-specific mortality, 2) assess space use and habitat selection, and 3) estimate survival of white-tailed deer fawns with reference to habitat variables.

Study Area

Our study took place from 2015-2017 in a 10 km² area in Boone County, Iowa, USA. We worked on both private (35%) and public (65%) lands along the Des Moines River. Public lands included Ledges State Park (5 km²) and McCoy Wildlife Management Area

(1.75 km²). Steep sandstone ridges and ravines provided topographical variation with a maximum elevation change of 75 m. Our study area was 80% woodland, 11% grassland, 6% agriculture, 2% developed (structures and roads), and 1% water/wetland (calculated from Iowa Department of Natural Resources [IDNR] 3 m land cover raster, 2009). Common tree species included white oak (*Quercus alba*), red oak (*Q. rubra*), American linden (*Tilia americana*), and black walnut (*Juglans nigra*). Herbaceous cover was primarily Virginia creeper (*Parthenocissus quinquefolia*), sedges (*Carex* spp.), *Sanicula* spp., American hogpeanut (*Amphicarpaea bracteata*), and pointed-leaved tick trefoil (*Desmodium glutinosum*). Prairie grasses included big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparius*), switchgrass (*Panicum virgatum*), and Canada wild rye (*Elymus canadensis*) (Johnson-Groh 1985). Coyotes and bobcats were present in our study area at low densities. From 1 October to early January each year, McCoy Wildlife Management Area was open to all forms of legal deer hunting and Ledges State Park was open to antlerless-only archery hunts.

Methods

Search and Capture

We captured neonatal fawns during late May and early June 2015-2017. We grid-searched woodland and grassland habitat on foot with crews of 2-8 searchers to locate bedded fawns. We also opportunistically located fawns by observing doe behavioral cues (Downing and McGinnes 1969, Huegel et al. 1985b) and from sightings reported by the public. We captured fawns by hand at their bed site or after a brief (<10 m) chase. We blindfolded fawns to reduce external stimuli and, if we captured them at a bed site, moved them ≤ 10 m from the bed site to avoid disturbing vegetation. We placed fawns in a clean pillowcase and weighed them to the nearest 0.01 kg using a spring scale. We visually

determined sex and then measured new hoof growth to the nearest 0.01 mm using digital calipers to estimate age (Haugen and Speake 1958, Brinkman et al. 2004*b*). We fit each fawn with an expandable, breakaway VHF radio collar (model M4210, Advanced Telemetry Systems [ATS], Isanti, MN, USA) programmed with a 4- or 12-hour mortality switch (Diefenbach et al. 2003). We wore unscented nitrile gloves for all handling and rubbed fawns with native vegetation before release to minimize human scent transfer. We handled fawns for ≤ 15 minutes to minimize the risk of handling-related abandonment. After processing, we returned fawns to their bed sites. After release, we searched around the capture site to locate possible siblings. The Iowa State University Institutional Animal Care and Use Committee approved our handling methods (Permit No. 2-15-7954-W). We collected fawns under IDNR Scientific Collector Permit No. SC871.

Monitoring and Cause-specific Mortality

We monitored fawns using radio telemetry 1 to 4 times per day from capture through 31 August and twice per week until 31 December of their capture year. If we could not detect a radio signal from a collar using a handheld Yagi antenna or vehicle-mounted omnidirectional antenna and receiver (model R410, ATS) during a monitoring period, we expanded the search area and attempted again during the following monitoring period. If a signal was not detected after two consecutive days, we assumed the fawn had left the study area or the collar had failed, and we censored it from survival analysis at its last known signal date. When we detected a mortality signal, we located the collar as quickly as possible. We examined the collar, carcass, and surrounding area for indications of cause of death including blood, wounds, and tracks. We classified the most likely cause of mortality as disease, suspected predation, harvest, starvation, vehicle collision, or unknown based on the condition of the remains and surrounding area. We submitted intact carcasses to the Veterinary

Diagnostic Laboratory at Iowa State University for gross necropsy. If we found a collar and no remains or indication of mortality (hair, blood, drag marks, etc.), we classified the fate as unknown and censored the individual from subsequent survival analyses. We quantified mortalities and causes in time intervals of 0-30 days, 31-60 days, and 61 days-7 months post-capture. Seven months is not a commonly reported survival interval in fawn studies, but we chose it to encompass exposure to hunting. We avoided using date cut-offs (e.g., 1 October or 31 December) to ensure equal lengths of monitoring per fawn regardless of date of capture.

Home Range Estimation and Space Use

We located fawns by radio telemetry using a handheld Yagi antenna and receiver. We used a rotating 4-hour block schedule (e.g., 0600-1000 h, 1000-1400 h) through 31 August to stratify fawn locations throughout the day. We included overnight monitoring blocks in 2015, but restricted our monitoring to daylight hours (0600 – 2200 h) in 2016 and 2017. We visually confirmed the location of fawns tracked with telemetry at least once per week from capture to 31 August and recorded their location to within ≤ 10 m using a handheld GPS. After 31 August, we visually confirmed fawn locations on an *ad hoc* basis. We estimated fawn locations through triangulation when we did not visually locate them. For each triangulation, we took a set of ≥ 3 bearings within 45 minutes using a handheld compass. We estimated locations using the maximum likelihood estimator in program LOAS (version 4.0.3.8, Ecological Software Solutions LLC, Hegymagas, Hungary; Lenth 1981). We only included locations with a 95% χ^2 error ellipse of ≤ 2 ha in our analysis (Kilgo et al. 2014).

We created home ranges for fawns in time intervals of 0-30 days, 0-60 days, and 0 days-7 months post-capture. We only included fawns that had ≥ 30 locations within the interval of interest (Seaman et al. 1999, Kernohan et al. 2001). We estimated 0-60 day and 0

day-7 month home ranges for fawns that had ≥ 30 locations in later portions of an interval (i.e., 31-60 days, 61 days-7 months) even if they did not have 30 locations from 0-30 days post-capture. We estimated 95% kernel density home ranges using the least squares cross validation (LSCV) bandwidth estimator in Geospatial Modeling Environment (GME; version 0.7.4, Spatial Ecology LLC). We calculated the area and habitat composition of each home range in ArcGIS (version 10.3, Environmental Systems Research Institute, Inc., Redlands, CA, USA) using a 3 m high-resolution land cover raster layer (IDNR 2009). We limited analysis to habitat classes that we believed may have implications for fawn survival: woodland, grassland (which included pasture, prairie, and lawns), agriculture (which included row-crop and all other types), and roads. We fit mixed-effects models with year as a random effect to test for relationships between sex and time interval on home range area and habitat composition. We evaluated significance of fixed effects using ANOVA and t-tests at $\alpha = 0.05$.

We assessed habitat selection for male and female fawns for each time interval using Manly's selection ratio (Manly et al. 2002) in package 'adehabitat' in R (R Version 3.3.3, www.r-project.org). We tested third-order habitat selection, where available habitat is unique to each individual. We conditioned available habitat on an individual's home range and we quantified habitat use as the total number of locations of an individual in each habitat class. Manly's selection ratio provides a mean 'weight' value for each habitat class. Values >1 indicate selection for a habitat class and values <1 indicate selection against a habitat class. We considered selection significant when the 95% confidence interval for a value did not include 1. We omitted the road habitat class from the habitat selection analysis because our definition of use required fawns to be physically located on a road, which rarely occurred.

Survival Estimates

We estimated fawn survival for the time intervals described above using the Known Fate analysis in Program MARK (White and Burnham 1999). We used a staggered entry design where individuals entered the analysis on date captured. We left-censored all dropped or lost collars to be as conservative as possible in our estimates. In order to model the effects of key habitat variables on fawn survival, we calculated the proportion of nearby woodland and agricultural habitat for each fawn at each occasion within an interval by creating a buffer around locations of all fawns in ArcGIS. Because we located each fawn multiple times per day, we chose a single location per day per fawn. We selected the location closest to noon per day per fawn. Because fawns become more mobile as they age, we specified different buffer radii for each time interval. We selected the buffer radius for each interval based on mean daily fawn movements calculated across all fawns for that interval. We estimated mean daily fawn movement by averaging the linear distance between locations of individual fawns recorded 12 – 36 hours apart to account for variation in our monitoring schedule. Mean daily fawn movement and associated buffer radius was 120 m for the 30-day interval, 155 m for the 60-day interval, and 170 m for the 7-month interval.

We considered models including constant survival $\{S(\cdot)\}$, linear trend $\{(S(T))\}$, quadratic trend $\{S(T^2)\}$, weekly survival $\{S(\text{Weekly})\}$, survival between non-hunting and hunting seasons $\{S(\text{Hunt})\}$, interval-specific survival $\{S(30, 60)\}$, behavioral stage $\{S(\text{Hider})\}$, and covariate-specific models. Covariates of interest included year, sex, and proportion of woodland habitat and agricultural habitat which were calculated as described above. We ranked survival models using Akaike's Information Criterion corrected for small sample size (AIC_c ; Burnham and Anderson 2002) and selected the model with the smallest AIC_c as the best model for each interval. We considered models to have no support if they

were >2 AIC_c from the best model (Δ AIC_c). When a main effect model was supported, we considered additive and interactive effect models using that effect. We generated initial model parameters using frequentist statistics, but lack of convergence led us to use Bayesian Markov chain Monte Carlo estimation. We report all parameter estimates with 95% credible intervals (CI) and consider them significant when the 95% CI does not overlap zero.

Results

Capture and Cause-specific Mortality

We captured and radio-collared 48 fawns (22 male, 26 female) from 2015-2017 (12 in 2015, 24 in 2016, 12 in 2017). Mean date of capture was 27 May (range: 15 May – 17 June). Fawn weight at capture \pm standard error (SE) averaged 3.9 ± 0.13 kg. We recorded 21 mortalities (9 male, 12 female) between capture and 31 December of the capture year (4 in 2015, 12 in 2016, 5 in 2017). We recorded 7 mortalities within 30 days of capture, 2 in the period 31-60 days post-capture, and 11 in the period 61 days-7 months post-capture. We attributed recorded mortalities to disease (9), suspected predation (4), harvest (3), starvation (1), and vehicle collision (1, Table 1.1). We were unable to determine a likely cause for 3 mortalities. Disease mortalities included epizootic hemorrhagic disease [EHD] (5), enteritis (3), and sepsis (1). We submitted samples from the first suspected EHD mortality to the U.S. Department of Agriculture National Veterinary Services Laboratories to confirm the gross necropsy diagnosis of EHD by polymerase chain reaction (PCR) test. Testing identified EHD virus serotype 6. We classified later EHD mortalities solely by necropsy.

Home Range Estimation and Space Use

We recorded 4,280 fawn locations using visual relocations and triangulation estimates between capture and 31 December across the 3 years of the study. We estimated 95% kernel density home ranges for 36 fawns from 0-30 days post-capture, 33 fawns from 0-60 days

post-capture, and 29 fawns from 0 days-7 months post-capture. Home ranges averaged 21.22 ± 2.74 ha for the 0-30 day interval, 25.47 ± 2.87 ha for the 0-60 day interval and 30.59 ± 2.37 ha for the 0 day-7 month interval. Home range size was significantly different among intervals ($F_{2, 90} = 4.16$, $P < 0.05$; Table 1.2), with 7-month home ranges being larger than 30-day ranges ($t_{92} = 2.88$, $P < 0.01$). Males had larger home ranges than females across all intervals ($t_{92} = 2.66$, $P < 0.01$; Table 1.2).

Woodland comprised $>60\%$ of home range habitat in all time intervals, followed by grassland ($>15\%$), agriculture ($<10\%$), and roads ($<5\%$) (Table 1.3). Woodland and grassland, woodland and agriculture, and woodland and roads were negatively correlated (-0.81 to -0.71). Grassland and roads, and agriculture and roads were positively correlated (0.39 to 0.64). Given these correlations, we ran individual mixed-effects models with each habitat class of interest as the response variable to test for differences in home range habitat composition among time intervals or between male and female fawns. The average amount of woodland in home ranges did not differ significantly among time intervals ($F_{2, 92} = 0.22$, $P > 0.05$; Table 1.3) or between males and females ($t_{92} = -1.01$, $P > 0.05$; Table 1.4). The average amount of grassland in home ranges did not differ significantly among time intervals ($F_{2, 92} = 0.14$, $P > 0.05$; Table 1.3) or between males and females ($t_{92} = 0.86$, $P > 0.05$; Table 1.4). The average amount of agriculture in home ranges did not differ significantly among time intervals ($F_{2, 92} = 0.31$, $P > 0.05$; Table 1.3) or between males and females ($t_{92} = 0.79$, $P > 0.05$; Table 1.4). The average amount of road in fawn home ranges did not differ significantly among intervals ($F_{2, 92} = 0.13$, $P > 0.05$; Table 1.3) or between males and females ($t_{92} = 0.23$, $P > 0.05$; Table 1.4).

Male fawns did not exhibit habitat selection within their 30-day home ranges ($\chi^2_{19} = 27.38$, $P > 0.05$), but did at 60 days ($\chi^2_{21} = 43.61$, $P < 0.01$) and 7 months ($\chi^2_{18} = 50.81$, $P < 0.001$). However, individual habitat selection ratios were not significant in any interval (Figure 1.1). Female fawns did not exhibit habitat selection within their 30-day home ranges ($\chi^2_{23} = 32.01$, $P > 0.05$), but did at 60 days ($\chi^2_{33} = 68.00$, $P < 0.001$) and 7 months ($\chi^2_{35} = 63.45$, $P < 0.01$). Female fawns selected against agricultural habitat in all time intervals, but did not select for or against woodland or grassland habitat (Figure 1.2).

Survival Estimates

Our top model for survival through 30 days post-capture included only proportion of nearby woodland, which had a significant positive effect on daily survival ($\beta = 3.81$, 95% CI was 2.08, 5.71; Tables 1.5 and 1.6, Figure 1.3). Estimated 30-day survival from mean date of capture was 0.78 ± 0.07 . Our top model for 60-day survival also included only proportion of nearby woodland, which had a positive effect on daily survival ($\beta = 5.43$, 95% CI was 3.43, 7.45; Tables 1.7 and 1.8, Figure 1.4). Estimated 60-day survival was 0.69 ± 0.08 . Our top model for 7-month survival included an interaction between available woodland and a quadratic trend (Table 1.9). Despite being the top model, no parameter estimates were significant (Table 1.10). Estimated 7-month survival was 0.31 ± 0.02 . Models including sex or year as a main effect were not competitive ($\Delta AIC_c > 2$) in any intervals.

Discussion

Disease was the primary source of fawn mortality in central Iowa, followed by suspected predation and harvest. Most mortality occurred 61 days-7 months post-capture. Fawn home ranges were small and composed primarily of woodland in all time intervals and the amount of nearby woodland had positive effects on survival estimates. Female, but not male, fawns avoided agriculture within their home ranges.

Cause-specific mortality

Disease accounted for nearly half of all recorded mortalities in our study. In comparison, other Midwestern fawn studies reported little-to-no disease mortality (e.g., 1 in Huegel et al. 1985a, 2 in Pusateri Burroughs et al. 2006). EHD was responsible for 55% of all our recorded disease events. EHD is a virus spread by insects that typically occurs in late summer and early fall (Davidson 2006). Outbreaks of EHD occur sporadically but can cause significant mortality in local deer populations over a short period of time (Fischer et al. 1995). We observed EHD mortality only in 2016 and the first EHD mortality occurred in July and continued into October, when sustained frost likely killed the midges responsible for spreading the disease (Jones et al. 1977). All other disease mortalities occurred within 2 weeks of capture. Previous studies considered disease to be a mortality risk only early in a fawn's life (Huegel et al. 1985a, Pusateri Burroughs et al. 2006). Our results indicate that outbreaks of sporadic diseases like EHD can account for a large portion of fawn mortality in years when they occur.

Unlike many previous fawn survival studies, predation was not the primary source of mortality in our study. We attributed only 19% of recorded mortalities to suspected predation and we may have misattributed instances of scavenging as predation mortality. Previous studies in Iowa and Minnesota/South Dakota attributed 77% and 80% of fawn mortality to predation (Huegel et al. 1985a, Grovenburg et al. 2011). We did not attempt to determine predator species, but the only known fawn predators in our study area were coyotes, bobcats, and domestic dogs. Coyotes are responsible for most documented fawn predation in the Midwest (Huegel et al. 1985a, Rohm et al. 2007). Coyotes are visual hunters and experience varied success depending on landscape composition (Wells and Lehner 1978, Nixon et al. 1991). Despite a predator community similar to the previous Iowa fawn study, we recorded

much lower levels of predation (Huegel et al. 1985a). Their study area was only 11% woodland, compared to 80% in our study. While some studies found no relationship between available cover and fawn survival (Kilgo et al. 2014, Chitwood et al. 2015), Piccolo et al. (2010) found that coyote predation on fawns was higher at a site with low vegetation density and height compared with another, more vegetated, site. Nearly all of our fawn locations occurred in woodland (70%) and grassland (22%, which included lawns and pasture, but was primarily tallgrass prairie; P. McGovern, unpublished data), which meant fawns had easy access to cover which may have reduced predation rates. We also captured and continued to locate fawns in areas of high human traffic on public land (campgrounds, picnic areas, etc.) and human activity may have prevented coyotes from searching these areas for hiding fawns (George and Crooks 2006).

Mortality in other fawn studies is often concentrated in the first 30 days of life and primarily due to predation (Cook et al. 1971, Grovenburg et al. 2011, Shuman et al. 2017). Most of our recorded mortalities occurred more than 60 days after capture. In studies with high fawn survival and low predation rates, Pusateri Burroughs et al. (2006) and Hiller et al. (2008) recorded 70.6% and 50% of their respective mortalities after 60 days of age. They attributed these mortalities primarily to harvest and vehicle collisions. We only recorded a single vehicle collision mortality, but harvest was our third-largest source of mortality. As stated above, EHD caused extensive mortality in fawns >60 days post-capture. When predation is not a strong pressure early in life, more fawns survive to be exposed to other, late-season, sources of mortality including harvest and disease outbreaks.

Space Use

Our estimated home ranges were smaller than most home ranges reported at comparable time intervals in the Midwest. Fawn home ranges in southern Michigan averaged

40.9 ha through 2 months (Hiller et al. 2008) and 62.65 ha through 27 weeks (Pusateri Burroughs et al. 2006), in contrast to our estimates of 25.47 and 30.49 ha through 60 days and 7 months (28 weeks) respectively. In South Dakota and southern Minnesota, summer home ranges averaged 92.2 – 193.7 ha over a 3-year span. Our fawn home ranges were most similar in size and composition to 3-month home ranges in two suburban Chicago forest preserves, which averaged 12 and 27 ha (Piccolo et al. 2010). Fawns at the preserve with low understory vegetation density moved farther and had larger mean home ranges than fawns at a preserve with greater understory vegetation. Agriculture comprised 52-54% of the Michigan study areas (Pusateri Burroughs et al. 2006, Hiller et al. 2008) and 59-86% of the South Dakota and Minnesota study areas (Grovenburg et al. 2011). In contrast, our study area was >90% woodland and grassland habitat and only 6% agriculture. Agricultural land provides less permanent cover than woodland or grassland. Fawns, especially those under 2 months old, rely on access to cover (Huegel et al. 1986). The availability of woodland and grassland in our study area meant that fawns did not have to travel far to find suitable cover which may be responsible for their smaller home ranges.

Female fawns in our study avoided agricultural habitat within their home ranges at all time intervals. Fawns in South Dakota avoided agriculture in early summer before transitioning to selection for corn when it matured in late summer (Grovenburg et al. 2012*b*). Fawns in Lower Michigan also avoided agriculture and other areas of low cover while selecting for woodland within their home ranges (Hiller et al. 2008). Cover is important to fawns for thermoregulation as well as avoiding predation (Huegel et al. 1986, Piccolo et al. 2010). In Iowa, woodland provides consistent vegetative cover, whereas row crop agriculture provides little-to-no cover during May and early June when fawns are born and at their most

vulnerable to predation. We did not detect a shift in fawn habitat selection regarding agriculture over time, but our study area included a much greater percentage of permanent cover (i.e., woodland, prairie; >90%) than agriculture (<10%). Transitions in habitat selection as documented by Grovenburg et al. (2012*b*) may be important in areas with little permanent cover.

Previous studies did not investigate sex-specific habitat selection (Hiller et al. 2008, Grovenburg et al. 2012*b*). We had greater statistical power to detect habitat selection in female fawns than male fawns because of uneven sample sizes (at 30 days: 21 females, 15 males; 60 days: 21 females, 12 males; 7 months: 19 females, 10 males). Small sample sizes of male fawns may have limited our power to detect selection. Alternatively, female fawns may be more cautious than males, move less, and may be more reluctant to use areas with lower cover (Jackson et al. 1972, Schwede et al. 1994).

Survival Estimates

Our 30-day fawn survival estimate of 0.78 was comparable to survival estimates from other fawn studies in the Midwest. Comparable 30-day survival estimates in previous studies included 0.86 in Iowa, and 0.93-0.97 in Michigan (Huegel et al. 1985*a*, Pusateri Burroughs et al. 2006). However, our survival estimate was much higher than those reported for fawns in southern Texas (0.07, Cook et al. 1971), South Carolina (0.29, Epstein et al. 1985), Louisiana (~ 0.32, interpreted from Figure 2, Shuman et al. 2017), Georgia (~ 0.43, interpreted from Figure 1, Nelson et al. 2015), and New Brunswick (0.47, Ballard et al. 1999). Fawn survival through 60 days in our study was similar to previous estimates from Lower Michigan (0.81, Hiller et al. 2008), Iowa (0.85, Huegel et al. 1985*a*), and southern Minnesota and South Dakota (0.89, Grovenburg et al. 2011). Our top model for both 30- and 60-day survival included only the nearby woodland habitat covariate. Woodland had a consistent, positive

effect on survival estimates for fawns even at low proportions (Figures 1.3 and 1.4). Large forest patches positively influenced fawn survival in southern Illinois (Rohm et al. 2007). Conversely, Grovenburg et al. (2011) found no effects of habitat variables including forest cover on fawn survival in Minnesota and South Dakota. The habitat composition of Rohm et al.'s study area (74% woodland and grassland, 17% agriculture) was similar to that of our study (91% woodland and grassland, 6% agriculture) and likely explains our similar results. As stated previously, cover is important for reducing fawn vulnerability to predation. Studies with low fawn survival estimates through 30 and 60 days all reported high levels of predation (Bartush and Lewis 1981, Kilgo et al. 2014, Shuman et al. 2017). The high proportion of woodland in our study may have facilitated increased fawn survival rates early in life by providing cover that reduced their predation risk.

Our survival estimate of 0.31 through 7 months post-capture was significantly lower than our 30- and 60-day estimates. The sharp decline in survival as well as the overall low estimate were different from comparable Midwestern fawn studies. Fawn survival through 6 months was 0.77 in an earlier study in Iowa (60-day: 0.85, Huegel et al. 1985a) and 0.67 in Michigan (60-day: 0.81, Hiller et al. 2008). Pusateri Burroughs et al. (2006) reported 220-day survival estimates of 0.76 and 0.85, and annual survival estimates of 0.76 and 0.75. Our estimate was more comparable to those fawn studies characterized by high rates of predation, even though predation was not the primary source of mortality in our study. Survival was 0.29 for fawns through 20 weeks of age (pre-hunting season) in Georgia (Nelson et al. 2015) and 0.38 through 34 weeks in Pennsylvania (Vreeland et al. 2004). The 7-month period we evaluated encompassed the transition of fawns from “hidiers” to “followers”, weaning, and hunting seasons. Fawns >60 days old are generally capable of escaping predators (Jackson et

al. 1972, Carroll and Brown 1977) and we recorded no suspected predation mortalities in fawns after 60 days post-capture. EHD was a source of significant mortality of fawns >60 days old in 2016. Additionally, more than half of our study area was open to hunting from 1 October to the end of monitoring each year and hunters harvested 3 fawns. The combination of EHD and harvest mortalities is the best explanation for our observed decline in fawn survival estimates through 7 months post-capture.

Management Implications

We provided estimates of fawn survival and space use in central Iowa for use in management decisions. Our findings that woodland habitat was positively associated with survival suggests that maintaining or restoring woodland habitat in areas of limited or temporary cover such as the agricultural Midwest is important. Sources of fawn mortality can vary among years and outbreaks of sporadic diseases like EHD can cause significant mortality. However, in our study, mortality from such sporadic events did not appear to significantly reduce overall fawn survival compared to years without EHD mortality.

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Tables

Table 1.1 Cause-specific mortality of white-tailed deer fawns, Boone County, Iowa, USA, 2015-2017.

Cause	N	Percent of Total Mortality
Disease	9	44
Suspected predation	4	19
Harvest	3	14
Vehicle collision	1	4.5
Starvation	1	4.5
Unknown	3	14

Table 1.2 Average home range area (in ha) of white-tailed deer fawns by sex, year, or time interval, Boone County, Iowa, USA, 2015-2017.

	Area (SE)
Males	31.31 (3.24)
Females	21.85 (1.48)
2015	27.78 (3.40)
2016	20.88 (1.82)
2017	34.53 (3.70)
30 days	21.22 (2.74)
60 days	25.47 (2.87)
7 months	30.59 (2.37)

Table 1.3 Average habitat composition of white-tailed deer fawn home ranges for time intervals of 0-30 days post-capture, 0-60 days post-capture, and 0 day-7 months post-capture, Boone County, Iowa, USA, 2015-2017.

Habitat Class	Percent Composition (SE)		
	30-day	60-day	7-month
Woodland	70.73 (4.22)	67.30 (4.33)	70.31 (3.97)
Grassland	17.16 (2.51)	19.08 (2.62)	19.12 (2.60)
Agriculture	8.21 (2.24)	9.47 (2.71)	6.74 (2.00)
Roads	3.90 (0.47)	4.15 (0.47)	3.83 (0.43)

Table 1.4 Habitat composition of male and female white-tailed deer fawn home ranges averaged across intervals of 0-30 days post-capture, 0-60 days post-capture, and 0 days-7 months post-capture, Boone County, Iowa, USA, 2015-2017.

Habitat Class	Percent Composition (SE)	
	Males	Females
Woodland	65.86 (4.04)	71.63 (2.99)
Grassland	20.50 (2.73)	17.10 (1.70)
Agriculture	9.60 (2.53)	7.35 (1.55)
Roads	4.04 (0.36)	3.92 (0.37)

Table 1.5 Candidate model set for survival of white-tailed deer fawns through 30 days post-capture, Boone County, Iowa, USA, 2015-2017. Wood: proportion of woodland habitat within 120 m of fawn locations, Ag: proportion of agriculture habitat within 120 m of fawn locations, (.): constant trend, T: linear trend, T²: quadratic trend, Sex: sex of fawn, Weekly: week of interval, Year: year of study. AIC_c: Akaike's Information Criterion corrected for small sample size, Delta AIC_c: difference in AIC_c between model and top model, AIC_c weights: model weight assigned by AIC_c, Num. Par: number of parameters in model.

Model	¹Delta AIC_c	AIC_c Weights	Model Likelihood	Num. Par
{S(Wood)}	0.00	0.61	1.00	2
{S(Ag)}	0.89	0.39	0.65	2
{S(T)}	19.14	0.00	0.00	2
{S(Weekly)}	19.30	0.00	0.00	8
{S(.)}	20.31	0.00	0.00	1
{S(Sex)}	20.38	0.00	0.00	2
{S(T ²)}	20.86	0.00	0.00	3
{S(Year+T)}	22.66	0.00	0.00	4
{S(Year)}	23.89	0.00	0.00	3

¹The AIC_c value of the top model was 88.56.

Table 1.6 Parameter estimates, standard deviation, and 95% credible intervals (CI) for top model {S(Wood)} of white-tailed deer fawn survival through 30 days post-capture, Boone County, Iowa, USA, 2015-2017. Wood: proportion of woodland habitat within 120 m of fawn locations 0-30 days post-capture.

Parameter	Mean	Standard Dev.	95% Lower CI	95% Upper CI
S intercept	3.32	0.38	2.60	4.10
Wood	3.81	0.95	2.08	5.71

Table 1.7 Candidate model set for survival of white-tailed deer fawns through 60 days post-capture, Boone County, Iowa, USA, 2015-2017. Wood: proportion of woodland habitat within 155 m of fawn locations, Ag: proportion of agriculture habitat within 155 m of fawn locations, (.): constant trend, T: linear trend, T²: quadratic trend, Sex: sex of fawn, Weekly: week of interval, Year: year of study, (30,60): interval-specific model. AIC_c: Akaike's Information Criterion corrected for small sample size, Delta AIC_c: difference in AIC_c between model and top model, AIC_c weights: model weight assigned by AIC_c, Num. Par: number of parameters in model.

Model	¹Delta AIC_c	AIC_c Weights	Model Likelihood	Num. Par
{S(Wood)}	0.00	1.00	1.00	2
{S(Ag)}	26.16	0.00	0.00	2
{S(T)}	47.87	0.00	0.00	2
{S(T ²)}	49.79	0.00	0.00	3
{S(Year + T)}	50.21	0.00	0.00	4
{S(30, 60)}	51.41	0.00	0.00	2
{S(Sex)}	52.11	0.00	0.00	2
{S(Weekly)}	52.67	0.00	0.00	12
{S(.)}	52.79	0.00	0.00	1
{S(Year)}	55.04	0.00	0.00	3

¹The AIC_c value of the top model was 89.08.

Table 1.8 Parameter estimates, standard deviation, and 95% credible intervals (CI) for top model {S(Wood)} of white-tailed deer fawn survival through 60 days post-capture, Boone County, Iowa, USA, 2015-2017. Wood 30: proportion of woodland habitat within 155 m of fawn locations 0-30 days post-capture. Wood 60: proportion of woodland habitat within 155 m of fawn locations 31-60 days post-capture.

Parameter	Mean	Standard Dev.	95% Lower CI	95% Upper CI
S intercept 30	2.51	0.40	1.75	3.31
Wood 30	5.93	1.16	3.75	8.23
S intercept 60	4.40	0.67	3.18	5.74
Wood 60	3.27	1.27	0.87	5.69

Table 1.9 Candidate model set for survival of white-tailed deer fawns through 7 months post-capture, Boone County, Iowa, USA, 2015-2017. Wood: proportion of woodland habitat within 170 m of fawn locations, Ag: proportion of agriculture habitat within 170 m of fawn locations, (.): constant trend, T: linear trend, T²: quadratic trend, Sex: sex of fawn, Weekly: week of interval, Year: year of study, Hider: behavioral stage, Pre/Post Hunt: hunting season status. AICc: Akaike's Information Criterion corrected for small sample size, Delta AICc: difference in AICc between model and top model, AICc weights: model weight assigned by AICc, Num. Par: number of parameters in model.

Model	¹ Delta AICc	AICc Weights	Model Likelihood	Num. Par
{S(Wood * T ²)}	0.00	0.95	1.00	6
{S(Wood + T ²)}	7.01	0.03	0.03	4
{S(Wood)}	9.30	0.01	0.01	2
{S(T ²)}	9.90	0.01	0.01	3
{S(.)}	13.38	0.00	0.00	1
{S(Hider)}	15.26	0.00	0.00	2
{S(Pre/Post Hunt)}	15.32	0.00	0.00	2
{S(T)}	15.35	0.00	0.00	2
{S(Ag)}	15.38	0.00	0.00	2
{S(Sex)}	15.38	0.00	0.00	2
{S(Year)}	16.77	0.00	0.00	3
{S(Year + T)}	18.76	0.00	0.00	4
{S(Weekly)}	43.28	0.00	0.00	34

¹The AICc value of the top model was 221.96.

*Table 1.10 Parameter estimates, standard deviation, and 95% credible intervals (CI) for top model $\{S(\text{Wood} * T^2)\}$ of white-tailed deer fawn survival through 7 months post-capture, Boone County, Iowa, USA, 2015-2017. Wood: proportion of woodland habitat within 170 m of fawn locations 0 days-7 months post-capture, T: linear trend, T^2 : quadratic trend.*

Parameter	Mean	Standard Dev.	95% Lower CI	95% Upper CI
S Intercept	4.81	0.48	3.90	5.79
Wood	0.37	0.67	-0.95	1.71
T	0.01	0.04	-0.06	0.07
T^2	0.00	0.00	0.00	0.00
Wood*T	0.07	0.04	-0.02	0.14
Wood* T^2	0.00	0.00	0.00	0.00

Figures

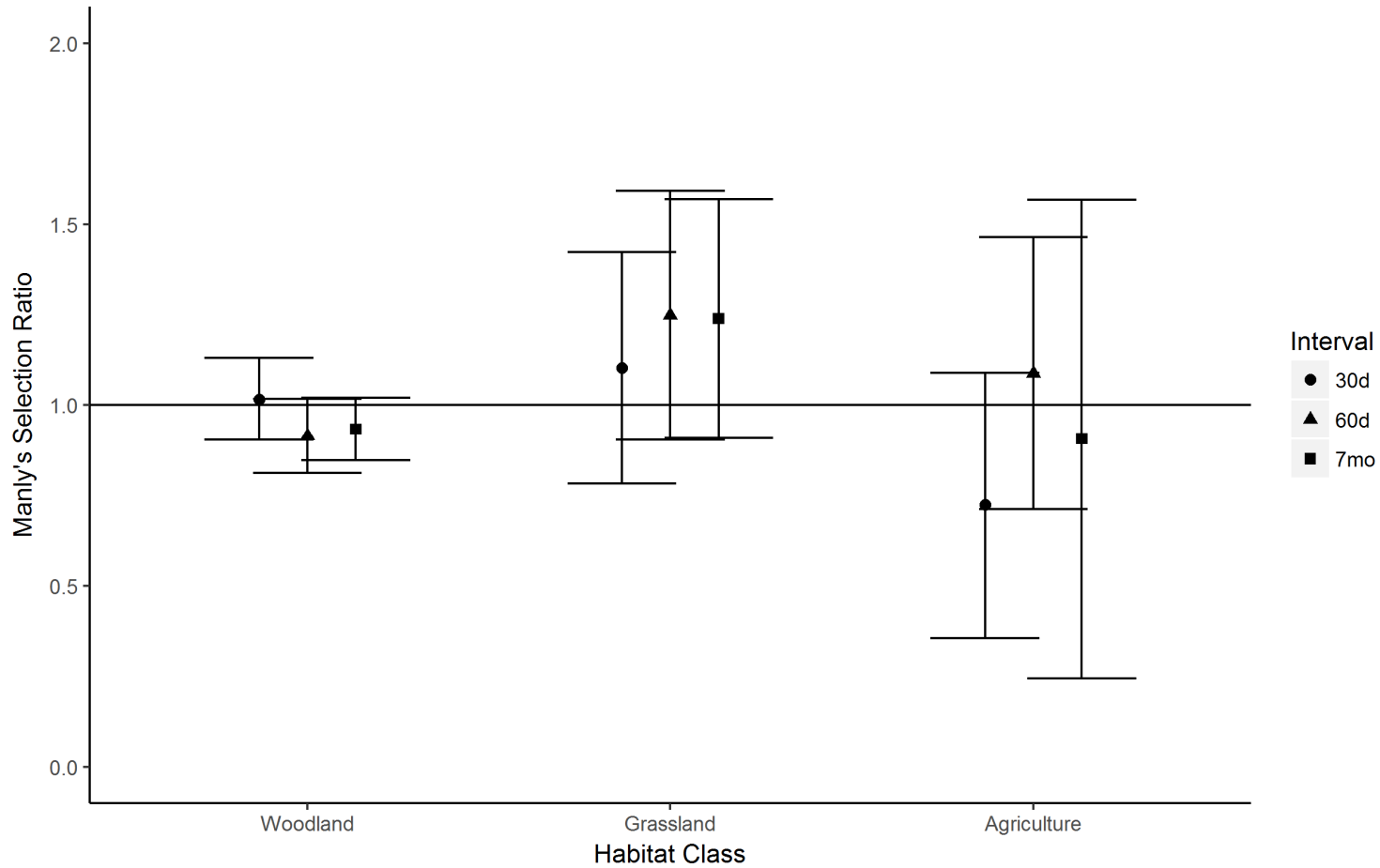


Figure 1.1 Habitat selection by male white-tailed deer fawns over intervals of 0-30 days post-capture, 0-60 days post-capture, and 0 days-7 months post-capture, Boone County, Iowa, USA, 2015-2017. Selection ratios > 1 indicate selection for a habitat class, while ratios < 1 indicate selection against a habitat class. Error bars represent 95% confidence intervals.

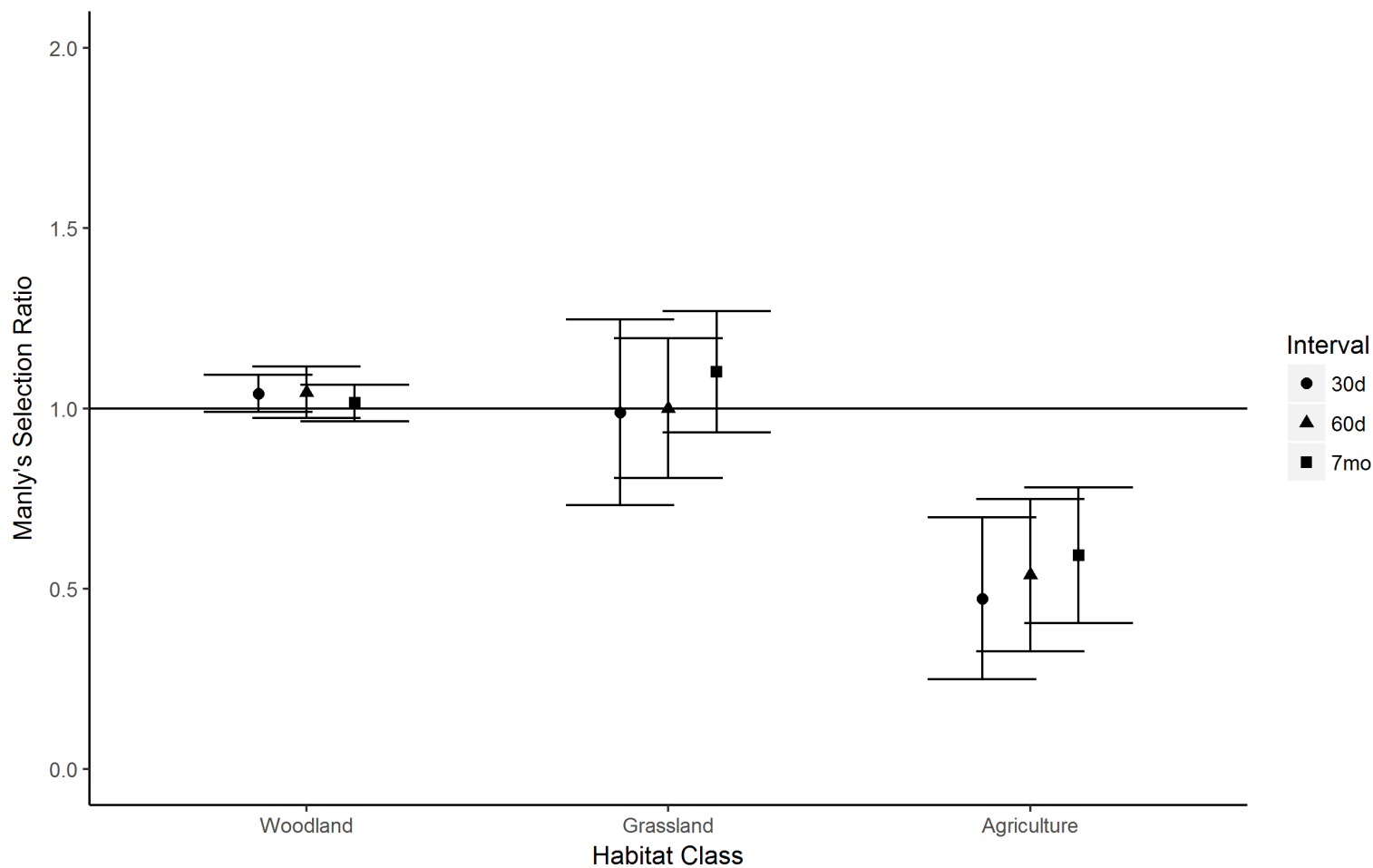


Figure 1.2 Habitat selection by female white-tailed deer fawns over intervals of 0-30 days post-capture, 0-60 days post-capture, and 0 days-7 months post-capture, Boone County, Iowa, USA, 2015-2017. Selection ratios > 1 indicate selection for a habitat class, while ratios < 1 indicate selection against a habitat class. Error bars represent 95% confidence intervals.

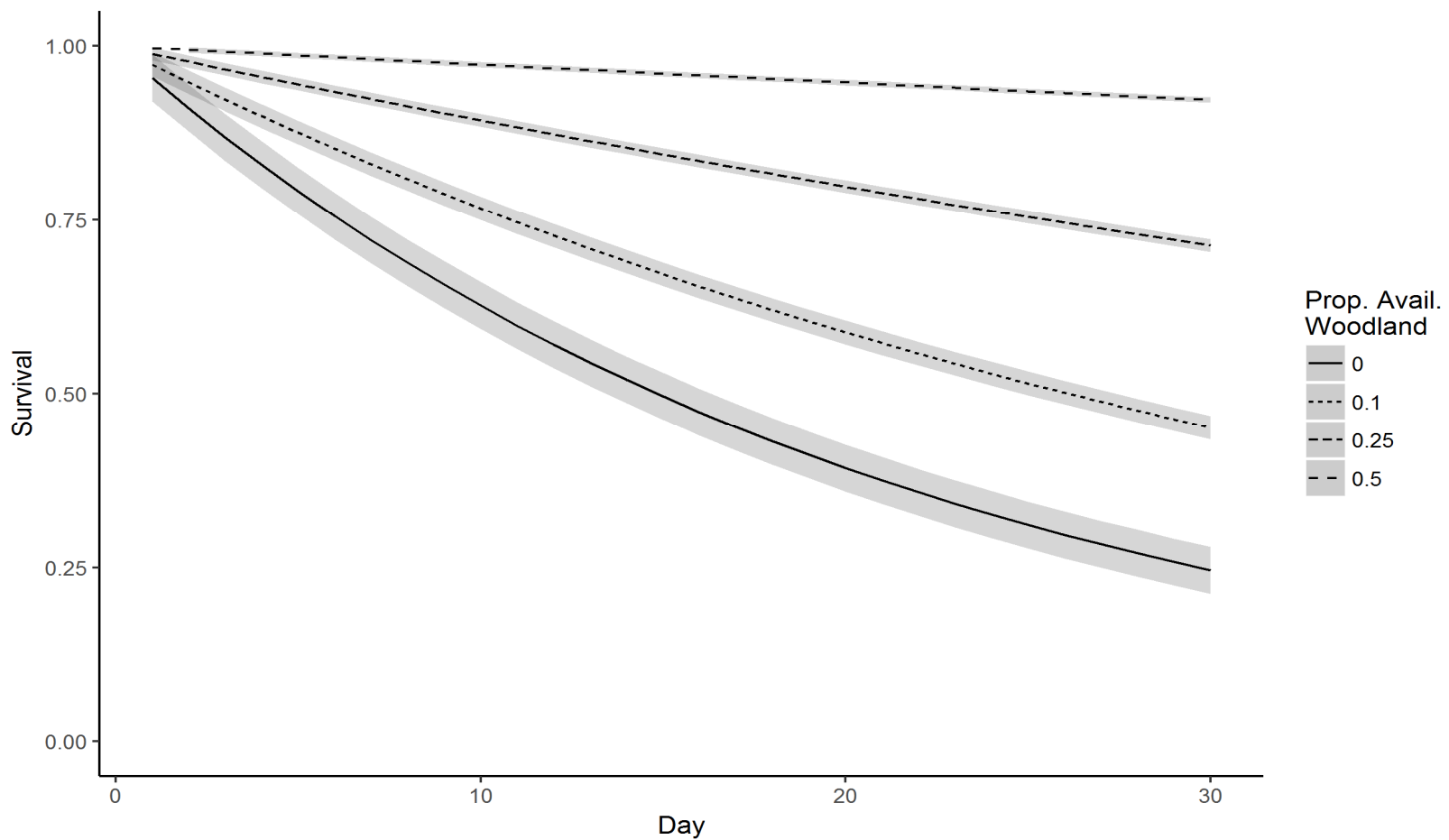


Figure 1.3 Predicted survival of white-tailed deer fawns to 30 days post-capture based on the top model $\{S(\text{Wood})\}$ for a range of proportions of woodland available within 120 m of fawn locations, Boone County, Iowa, USA, 2015-2017. Shaded regions indicate 95% credible intervals.

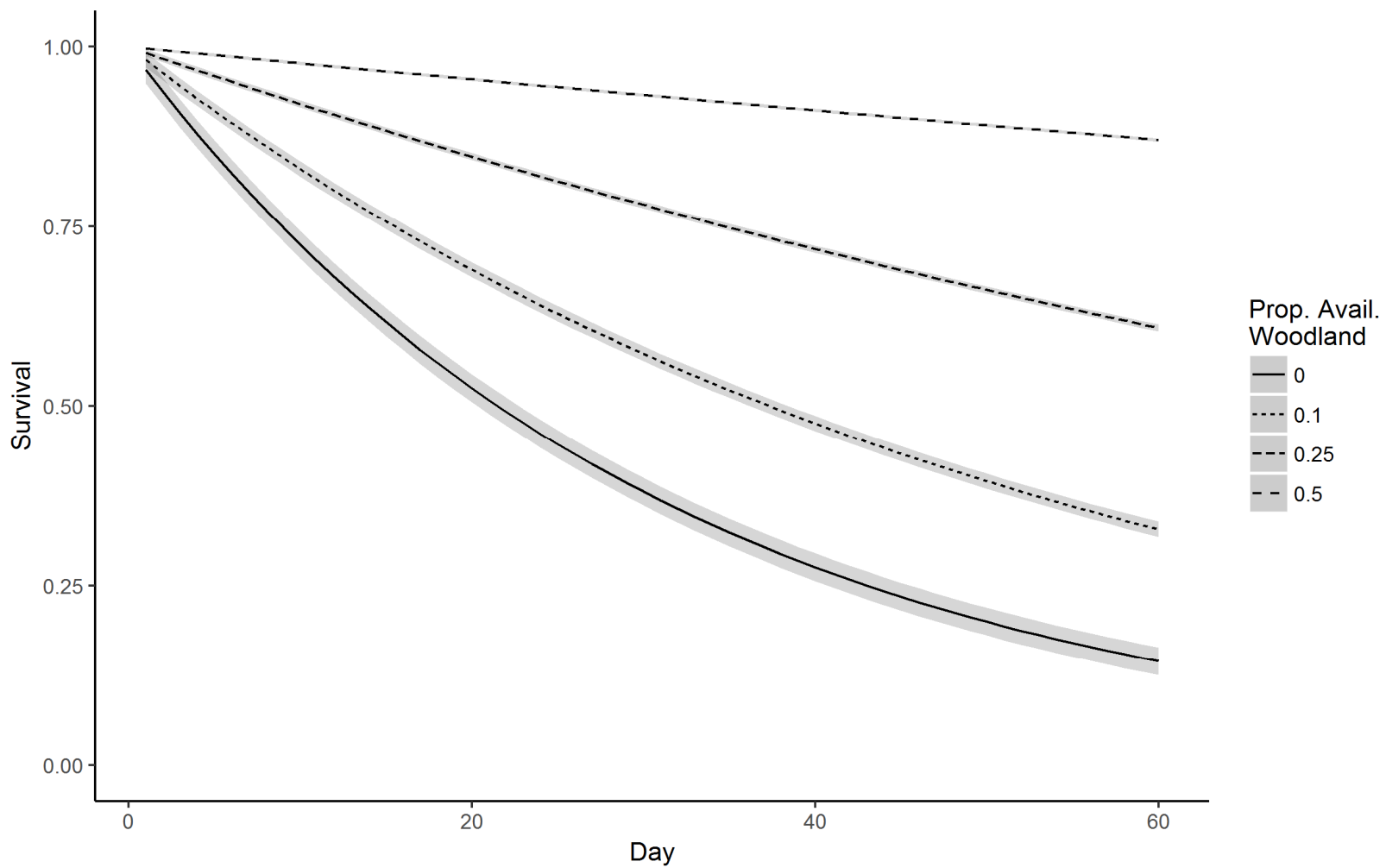


Figure 1.4 Predicted survival of white-tailed deer fawns to 60 days post-capture based the top model $\{S(Wood)\}$ for a range of proportions of woodland available within 155 m of fawn locations, Boone County, Iowa, USA, 2015-2017. Shaded regions indicate 95% credible intervals..

CHAPTER 2. THE IMPACTS OF SLOPE, FAWN MOBILITY, AND OBSERVER EXPERIENCE ON RADIO TELEMETRY ERROR

Abstract

Radio telemetry is an important and frequently used method to monitor the survival and space use of wildlife. Distance from the subject, topography, and movement all affect the accuracy of telemetry locations. Estimated error metrics such as error polygons or confidence ellipses are used as proxies for location accuracy. We conducted field trials to test the impacts of slope, fawn mobility, and observer experience on the accuracy of radio telemetry locations estimated through triangulation. We also evaluated the relationship between confidence ellipse area and location error to determine area's usefulness as a predictor of location accuracy. Location error varied among sites along a slope ($P < 0.001$); however, distance between sites and observer, not slope position, was the most likely explanation. Location error did not differ significantly between experienced and inexperienced observers ($P > 0.05$), nor did location error decrease over time for inexperienced observers ($\beta = -0.004$, 95% CI was -0.013, 0.004). Location error for radio-collared fawns did not increase over time ($\beta = 0.005$, 95% CI was -0.001, 0.018). Location error increased with confidence ellipse area ($\beta = 0.87$, 95% CI was 0.57, 1.18), indicating area's usefulness as a predictor of location accuracy. Slopes did not consistently affect location accuracy in a way that would require evaluating slope estimates differently in space use analysis. Contrary to our predictions, observer experience and fawn mobility did not appear to have significant effects on location error of estimated fawn locations in our study.

Keywords: Accuracy, fawn, location error, movement, *Odocoileus virginianus*, radio telemetry, slope, triangulation, white-tailed deer

Radio telemetry is a commonly used tool in wildlife research to collect data that can be used to estimate survival (Huegel et al. 1985a, Nelson and Woolf 1987), movement (Ellis 1964, Heezen and Tester 1967), home ranges (Hiller et al. 2008, Grovenburg et al. 2011) and habitat selection of study animals (Rohm et al. 2007, Hiller et al. 2008). Animals are tagged with a radio transmitter programmed to emit a specific radio frequency. Using specialized antennae and receivers, observers can detect the signal and locate the transmitter by homing in on increasing signal strength (White and Garrott 1990). Typically, telemetry studies fall into one of two categories: using telemetry to physically locate and observe tagged individuals (e.g., Schwede et al. 1993) or monitoring survival and estimating locations without physically locating the individual (e.g., Hiller et al. 2008). Directly observing an animal carries an inherent risk of altering that animal's behavior, which radio telemetry gives researchers the opportunity to avoid (Slade et al. 1965, White and Garrott 1990). Observers can estimate animal locations by taking multiple directional bearings on the signal from known locations and triangulating the position of the signal (Lenth 1981, White and Garrott 1990). However, estimated locations have an inherent amount of error (Heezen and Tester 1967).

Radio telemetry operates using line-of-sight between a transmitter and receiver and is subject to errors in signal location due to factors including the distance between transmitter and receiver (Slade et al. 1965, Wallingford and Lancia 1991), topography (Ellis 1964, Garrott et al. 1986), vegetation density (Ellis 1964, Grovenburg et al. 2013), and transmitter height (Townsend et al. 2007, Grovenburg et al. 2013). As the distance between transmitter and receiver increases, bearing error (the difference between the observed bearing to the transmitter and the true bearing) increases (Slade et al. 1965). Signal bounce, or the reflection

of radio waves off angled or sheer surfaces, also increases bearing error (Garrott et al. 1986). Dense vegetation, buildings, and exposed rock faces can all cause signal bounce (Ellis 1964, Garrott et al. 1986, Grovenburg et al. 2013). Conversely, increases in transmitter height reduce bearing error (Townsend et al. 2007, Grovenburg et al. 2013). Estimated locations are calculated using observed bearings; as bearing error increases, so does location error (the distance between the estimated location of the transmitter and its true location). Location error can bias studies of habitat selection by placing estimated locations in incorrect habitat types (White and Garrott 1986, Nams 1989, Samuel and Kernow 1992) or movement by overestimating the distance between locations (Heezen and Tester 1967, Kauhala and Tiilikainen 2002).

The topography of a study area can have pronounced effects on location error (Ellis 1964). Signal bounce is more common in areas of varied topography because of exposed rock faces, slopes, or narrow ravines that reflect the signal (White 1985, White and Garrott 1990). Lack of clear line-of-sight between transmitter and receiver in rugged landscapes further increases signal bounce and reduces location accuracy (White 1985, Garrott et al. 1986). Topography is static and generally does not change over the course of a study, in contrast to the study animals themselves.

The life history of an animal can affect the estimated transmitter location (Townsend et al. 2007). In ungulates such as white-tailed deer (*Odocoileus virginianus*), predator avoidance strategies change during development (Lent 1974). During the first 4-6 weeks of life, neonates practice a “hider” strategy, spending much of their time lying prone and relying on their cryptic coloration and concealment provided by vegetation to avoid notice (Lent 1974). As development continues, neonates transition to a “follower” strategy and spend

more time upright and moving. Transmitters used in neonate studies are typically collar-style models placed around the neck of an individual (Diefenbach et al. 2003). During the “hider” stage, the transmitter is often at or just above ground level. As neonates become “followers”, the transmitter will be higher above ground on average. This transition presents potentially confounding effects on the accuracy of location estimates because the increased height of the transmitter may improve location accuracy (Townsend et al. 2007, Grovenburg et al. 2013). However, increased movement of the animal will reduce triangulation accuracy if locations are estimated from a series of sequential bearings (Schmutz and White 1990). As observers move from one bearing station to the next, the animal may move, rendering earlier bearings inaccurate. A previous study tested the relationship between changes in transmitter height based on fawn behavior and the accuracy of telemetry location estimates, but did not investigate the concurrent effect of increased movement on estimate accuracy (Grovenburg et al. 2013).

Experienced observers may be able to mitigate some of the factors that lead to increased location error of estimates. We did not find published literature on the relationship between observer experience and accuracy, but we hypothesize that increased experience with telemetry systems will result in increased accuracy of triangulation locations. Experienced observers may avoid taking bearings from locations prone to signal bounce (i.e., near buildings or exposed rock faces) or near features like overhead power lines, which can cause static feedback in receivers and make it more difficult to identify peaks in transmitter signal strength (Slade et al. 1965). Experienced observers may also identify peaks in signal strength more quickly than inexperienced observers, reducing the time between bearings and lessening the impact that animal movement has on a triangulation.

In most cases, observers do not know the true location of a tagged animal and cannot rely on location error to determine the accuracy of their location estimates. Observers must decide whether a location estimate is sufficiently accurate based on metrics calculated for each estimate such as size of the error polygon or confidence ellipse (Heezen and Tester 1967, Saltz and White 1990). These metrics are calculated using the intersection of observed bearings, corresponding error arcs, or maximum likelihood estimation (Lenth 1981). The underlying assumption is that increases in area of the error polygon or confidence ellipse are indicative of increases in location error (Saltz and White 1990). Few studies report error metrics along with telemetry estimates or describe how well they approximate location error (Saltz 1994). Given the variety of landscape- and species-specific factors that influence location error in telemetry studies, it is important to evaluate and report the relationship between error metrics and location error for each study system (Saltz 1994, Zimmerman and Powell 1995).

We conducted a series of field trials to investigate factors affecting the accuracy of radio telemetry location estimates of white-tailed deer fawns in central Iowa. Factors we considered included transmitter location relative to a slope, fawn behavioral stage, observer experience with radio telemetry systems, and gains in observer experience. We also tested the relationship between confidence ellipse area and location error to verify the use of area as a predictor of location error. We predicted that 1) triangulations of transmitters placed on slopes would be less accurate than transmitters on flat ground because of increased signal bounce from slopes, 2) triangulations of radio-collared fawns would become less accurate as fawn behavior changed and fawns moved more frequently, 3) triangulations by an experienced observer would be more accurate than those by inexperienced observers, 4)

triangulations by inexperienced observers would become more accurate over time, and 5) that there was a positive relationship between area of the error ellipse and location error.

Study Area

Our study took place in Boone County, Iowa, USA from May to August 2015-2017. Steep sandstone ridges and ravines provided topographical variation with an elevation range of 261 – 335 m (calculated from 3 m digital elevation model, Iowa Department of Natural Resources 2017). Our study area was 80% woodland, 11% grassland (including pasture, prairie, and lawns), 6% agriculture (including row-crop and all other forms), 2% developed (structures and roads), and 1% water/wetland (calculated from 3 m high-resolution land cover raster dataset, Iowa Department of Natural Resources 2009). Common tree species included white oak (*Quercus alba*), red oak (*Q. rubra*), American linden (*Tilia americana*), and black walnut (*Juglans nigra*). Herbaceous cover was primarily Virginia creeper (*Parthenocissus quinquefolia*), sedges (*Carex* spp.), *Sanicula* spp., American hogpeanut (*Amphicarpaea bracteata*), and pointed-leaved tick trefoil (*Desmodium glutinosum*). Prairie grasses included big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparius*), switchgrass (*Panicum virgatum*), and Canada wild rye (*Elymus canadensis*) (Johnson-Groh 1985).

Methods

Slope Trials

We designed an experiment to evaluate the effect of transmitter position along a slope on triangulation accuracy in 2017. We marked 6 transmitter sites along a transect bisecting a ravine (Figure 2.1). We marked 3 telemetry stations 75 m apart along a transect perpendicular to the transmitter site transect, with the center station located at the intersection of both transects (Figure 2.1). The nearest transmitter site was 35 m from the center telemetry

station. We divided transmitter sites into two groups of three based upon which side of the ravine they were located. We designated sites 1-3 on the side of the ravine closest to the transmitter transect and sites 4-6 on the opposite slope (Figure 2.2). Sequential sites (i.e., sites 1 and 2, sites 5 and 6) were located 25 m apart from one another, except for sites 3 and 4, which were 22 m apart. Sites 1 and 6 were 25 m from the top of the slope, on level ground, sites 2 and 5 were at the top of the slope, and sites 3 and 4 were 25 m downslope. For the trials, one person randomly placed a VHF fawn radio collar (model M4210; Advanced Telemetry Systems [ATS], Isanti, Minnesota, USA) at a site. Without knowing the location of the radio collar, another person collected bearings to the radio collar from each telemetry station using a handheld three-element Yagi antenna held at head-height, a receiver (model R410, ATS), and mirrored compass. We collected three bearings for each triangulation. We took ≥ 10 recordings of each radio collar site and telemetry station coordinates using a handheld GPS unit and averaged these recordings.

We estimated locations from bearing sets using the maximum likelihood estimator (Lenth 1981) in program LOAS (Version 4.0, Ecological Software Solutions, LLC, Hegymagas, Hungary). Bearing sets that did not produce a triangulation (i.e., ≤ 2 bearings intersected) or had a 95% chi-square error ellipse of > 2 hectares (ha) were omitted based on recommendations in the literature (Saltz and White 1990, Kilgo et al. 2014). We compared accuracy and precision of triangulation estimates using the distance in meters between estimated and known location (hereafter location error) and area of each estimate's 95% chi-square error ellipse (hereafter area). We tested differences in mean location error and area among sites using ANOVA at $\alpha = 0.05$. We evaluated pairwise comparisons between sites using a post-hoc Tukey comparison of means test at $\alpha = 0.05$.

Error Trials

We captured and radio-collared neonatal fawns during late May and early June 2015-2017. Crews of 2-8 people grid-searched woodland and grassland habitat on foot to locate bedded fawns. We also opportunistically located fawns by observing doe behavioral cues (Downing and McGinnes 1969, Huegel et al. 1985*b*) and from sightings reported by the public. Fawns were captured by hand at their bed site or after a brief (<10 m) chase. We blindfolded fawns to reduce external stimuli and, if we captured them at a bed site, moved them ≤ 10 m from the bed site to avoid disturbing vegetation. Fawns were placed in a clean pillowcase and weighed to the nearest 0.01 kg using a spring scale. We fit each fawn with an expandable, breakaway VHF radio collar (model M4210, Advanced Telemetry Systems [ATS], Isanti, MN, USA; Diefenbach et al. 2003). Handlers wore unscented nitrile gloves for all handling and rubbed fawns with native vegetation before release to minimize human scent transfer. We handled fawns for ≤ 15 minutes to minimize the risk of handling-related abandonment. After processing, we returned fawns to their bed sites. The Iowa State University Institutional Animal Care and Use Committee approved our handling methods (Permit No. 2-15-7954-W). We collected fawns under IDNR Scientific Collector Permit No. SC871.

To assess changes in telemetry accuracy as a function of fawn behavioral stage, we visually confirmed the location of radio-collared fawns after estimating their location through triangulation at least once per week from capture to 31 August. We triangulated fawns using a handheld three-element Yagi antenna, receiver, and mirrored compass. We recorded ≥ 3 bearings that were $\geq 25^\circ$ apart with a total elapsed time of <45 minutes for each triangulation. We visually located fawns within 30 minutes of triangulation by homing in on their collar

signal. We recorded bearing locations and the observed locations of fawns to within ≤ 10 m using a handheld GPS unit.

We placed fawn radio collars at locations throughout the study area from May – August 2015-2017 to evaluate observer accuracy on an immobile object (“test collars”). Observers were unaware of collar locations and triangulated the collars using the methods described above. After triangulating the collar, the observer physically located it and recorded its location to within ≤ 10 m using a handheld GPS unit. Each year, there was one experienced observer (>2 years of telemetry experience) and 2 inexperienced observers.

We estimated locations of test collars and collared fawns from bearing sets following the same protocol as described above for the slope trials. Location errors (with standard error) are reported in meters and represent the distance between the estimated and known locations. We compared location error between experienced and inexperienced observers using a t-test at $\alpha = 0.05$. We used linear regression to test for a relationship between location error and day of year using only inexperienced observer triangulations of test collars to determine if observers became more accurate over time. Linear regression was used to test for a relationship between location error and day of year using triangulations of collared fawns to determine if changes in fawn behavior (transitioning from “hider” to “follower”) affected location error. We combined triangulations from both stationary collars and collared fawns to test for a relationship between location error and area using linear regression. We log-transformed location error for each regression to meet assumptions of normality. Regression coefficients were considered significant when the 95% confidence interval (CI) did not include zero.

Results

Slope Trials

We conducted 183 trials, of which 155 trials resulted in a triangulation with an estimated error ellipse ≤ 2 ha. Collars located at site 6 were responsible for 67% ($n = 19$) of the omitted estimates. Sites had 10-34 replicates. Average location error across all sites was 31.66 m ($SE = 1.72$). Site had a significant effect on location error ($F_{5, 149} = 20.17$, $P < 0.001$; Table 2.2). Triangulation estimates of site 1 were more accurate than at all other sites. Triangulation estimates of site 5 were less accurate than all sites except site 6. Triangulation estimates of sites 2, 3, and 4 were not significantly different from each other (Table 2.3). Average area of the confidence ellipse was significantly different among sites ($F_{5, 149} = 8.39$, $P < 0.0001$; Tables 2.2 and 2.4). Area of the confidence ellipse was significantly smaller for estimates of sites on the near slope (sites 1-3) than sites on the far slope (sites 4-6; Table 2.2).

Error Trials

We captured and radio-collared 48 fawns in May and June 2015-2017. We collected 252 visual locations following triangulation of radio-collared fawns from capture to 31 August 2015-2017. Average location error for collared fawns was 52.57 m ($SE = 4.02$) and did not differ between experienced and inexperienced observers ($t_{250} = 0.53$, $P > 0.05$). Location error for collared fawns did not increase with day of year ($\beta = 0.005$, 95% CI was -0.001, 0.018; Figure 2.3).

We collected 114 triangulations of test collars from May-August 2015-2017. Average location error was 41.66 m (4.46) and did not differ between experienced and inexperienced observers ($t_{21} = 0.02$, $P > 0.05$). For test collars, location error did not differ with day of year for inexperienced observers ($\beta = -0.004$, 95% CI was -0.013, 0.004; Figure 2.4).

We collected 366 triangulations from both test collars and collars on fawns. Mean location error was 49.17 m (SE = 3.10). Mean area was 0.19 ha (0.02). Location error increased with area ($\beta = 0.87$, 95% CI was 0.57, 1.18; Figure 2.5).

Discussion

Examining the relationship between slope and triangulation accuracy, we found that location error varied among sites in the slope trials. Triangulation estimates at site 1 had the smallest mean location error and estimates at site 5 had the greatest mean location error, indicating that distance was more important than slope in determining triangulation accuracy. We tested the relationship between fawn mobility and triangulation accuracy and found that location error of radio-collared fawn estimates did not change over time. There was no significant difference in location accuracy between experienced and inexperienced observers. Location error of inexperienced observers did not change over time.

Slope Trials

We predicted that triangulation estimates of radio collars placed on slopes would be less accurate than estimates of radio collars on flat ground (Table 2.1). There was an overall difference in accuracy among sites, but it was not clearly a function of slope position. As expected, accuracies for the slope sites (sites 3 and 4, Figure 2.2) did not differ (Tables 2.1 and 2.3). However, they were also not different from sites 2 or 6, which were on level ground. Triangulations of radio collars at site 6 had a higher rate of failure than other sites (either because bearings did not intersect or the ellipse area was >2 ha). We may not have been able to differentiate accuracy of site 6 estimates from other sites because of the small sample size and large standard error (Table 2.2). Location estimates of site 2 did not have rates of failure similar to site 6, but they did have the second-most variability in accuracy (Table 2.2). Because our telemetry stations were located parallel to the ravine (Figure 2.1),

bearings taken from stations A and C to site 2 were likely affected by signal bounce from the downslope side of site 2. Signal bounce can increase bearing error, which then increases the location error of an estimate (Garrott et al. 1986). While we did not detect differences in location error between the slope sites and sites 2 or 6, we did determine that estimates for the slope sites were more accurate than for site 5. Estimates of site 5 had less variability than site 2, and may have been less affected by signal bounce because of the orientation of telemetry stations A and C relative to the ravine and site 5 (Table 2.2, Figure 2.1). Estimates of radio collar locations at the slope sites were more accurate than at site 5, yet less accurate than at site 1, despite the fact that both sites 1 and 5 were on level ground. Therefore, factors other than topography must be influencing location accuracy.

The distance between telemetry stations and site is the most plausible explanation for observed differences in location accuracy. Estimates of site 1, closest to the telemetry stations, were more accurate than all other sites. Estimates of site 5 were less accurate than sites 1-4, which were closer to the telemetry stations (Table 2.3, Figure 2.1). Slade et al. (1965) reported an increase in mean location error relative to distance between receiver and transmitter. However, they only observed increases in error at distances >1200 ft (366 m) and their mean location error was only 7.7 ft (2.3 m) in locations 0-600 ft (183 m) away. Our sites were located 35-170 m from telemetry stations and mean location error was 31.66 m. Distance may have had a greater effect on location error in our study compared to Slade et al. (1965) due to our study design. We used a handheld antenna held at head-height to triangulate transmitters whereas they used stationary towers located on high points in their study area. The increased height of the antenna increases the chances of a line-of-sight connection with the transmitter and reduces the risks of signal bounce (White 1985).

Conversely, the lower antenna height of handheld telemetry systems results in more frequently obstructed line-of-sight, and therefore increased signal bounce, bearing, and location error (White 1985, White and Garrott 1990). In handheld telemetry systems with large baseline error such as ours, increases in distance between the transmitter and receiver may compound error resulting from signal bounce in comparison to systems using tower- or vehicle-mounted antenna with smaller baseline error (Slade et al. 1965, Gilsdorf et al. 2008).

We expected slope to have a greater impact on triangulation accuracy than we observed. Our slopes were covered by soil, leaf litter, and vegetation in contrast to the exposed slope faces more common in mountainous terrain. Ellis (1964) suggested rock outcroppings as a cause of signal bounce. It is possible that slopes of exposed rock contribute more to signal bounce and increased location error than the soil-covered slopes in our study. Additionally, we exclusively took bearings from above the slope sites, pointing downslope. The height of the telemetry antenna increases line-of-sight and location accuracy (Slade et al. 1965, White 1985), therefore the orientation of our telemetry stations may have compensated for any negative effects of the slope.

Error Trials

Location error did not increase over time for estimates of collared fawns (Figure 2.3). As fawns age, they transition from sedentary to active life history strategies (Lent 1974). Fawns later in the summer were more likely to be moving compared to earlier in the summer (Lent 1974). We expected increased movement by fawns to result in greater location error because we triangulated fawns using sequential bearings. If a fawn moved during a triangulation, the first bearing would reference a different fawn location than later bearings and the resulting triangulation estimate would be less accurate than that of a stationary transmitter (Heezen and Tester 1967, Schmutz and White 1990). In addition to moving more,

later in the summer fawns will be standing more often than earlier in the summer (Lent 1974). Townsend et al. (2007) and Grovenburg et al. (2013) both reported increased location accuracy of transmitters placed higher off the ground. Increased accuracy from transmitter height may have countered increased error introduced by fawn movement and may explain why we did not detect a change in location error of collared fawns over time.

Contrary to our prediction, the experienced observer was not more accurate than inexperienced ones. It is probable that our triangulation protocol placed limits on some sources of error by requiring at least 3 bearings that were $\geq 25^\circ$ apart. By imposing a minimum difference in bearing angles, we increased the likelihood that observed bearings intersected and produced a usable location estimate (White and Garrott 1990). We also conducted our study in a relatively homogenous area. Our study area was predominantly woodland (80%) and grassland (11%), and 92% of fawn locations occurred in these habitats. Our study area lacked prominent topographical features (i.e., mountains, box canyons) and we were not tracking animals at great distances (> 800 m). All of these factors can affect signal bounce and location error (Slade et al. 1964, Garrott et al. 1986). The simplicity of our landscape and the short range at which we collected triangulations may reduce the need for experience to compensate for signal bounce. Increases in vegetation density in the study area could also have affected trends in location accuracy (Grovenburg et al. 2013). While inexperienced observers did not become less accurate over time, signal bounce from increased vegetation density might wash out concurrent increases in accuracy related to increased experience.

We tested the relationship between confidence ellipse area and location error to verify the use of area as a predictor of location error. We used confidence ellipse area because a

similar fawn study reported estimate accuracy criteria using area (Kilgo et al. 2014). Using their reported cut-off of 2 ha, our average location error was 49.17 m (SE = 3.10) and our average confidence ellipse area was 0.19 ha (0.02), which was much smaller than the 2 ha cut-off. We did not investigate alternative area cut-off values, but using the value reported in the literature resulted in a strong positive relationship between area and location error (Figure 2.5). An increase of 1 ha in confidence ellipse area corresponded to a 139% increase in location error. Our results suggest that using the area of the confidence ellipse is an adequate surrogate for location error when a transmitter's true location is unknown.

Management Implications

Landscape had little impact on the accuracy of triangulation estimates. The elevation gradients in central Iowa did not affect the accuracy of estimates to the extent that estimates were no longer reflective of an animal's true location. Landscapes comprised primarily of woodland or grassland habitat and lacking prominent topography may additionally minimize any effect of observer telemetry experience. We did not find evidence that fawn behavioral stage affected location error in our study enough to merit mitigation. Given that it is inefficient to determine location error for every triangulation estimate, researchers need another way to evaluate accuracy of estimates. Our results demonstrate that the area of the 95% chi-square confidence ellipse is a useful proxy for the accuracy of fawn triangulation estimates.

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Tables

Table 2.1 Predictions of pairwise comparisons for location error (distance between estimated and known locations) between sites for slope trials, Boone County, Iowa, USA, May-August 2017. Sites on the left of the table would have greater (+), less (-), or equal (=) mean location error compared to sites along the top of the table. Site positions are illustrated in Figure 2.1.

Site	1	2	3	4	5	6
1		=	-	-	-	-
2	=		-	-	-	-
3	+	+		=	+	+
4	+	+	=		+	+
5	+	+	-	-		=
6	+	+	-	-	=	

Table 2.2 Average location error (distance in meters between estimated and known locations), average area (in ha) of 95% chi-square confidence ellipse, and number of triangulations at each site during slope trials, Boone County, Iowa, USA, May-August 2017. Site positions are illustrated in Figure 2.1.

Site	Location error (SE)	Area (SE)	Number of trials
1	11.33 (1.66)	0.04 (0.02)	27
2	29.08 (4.13)	0.14 (0.04)	26
3	30.03 (2.07)	0.09 (0.02)	30
4	26.89 (3.00)	0.40 (0.07)	28
5	53.35 (3.74)	0.36 (0.07)	34
6	37.73 (5.52)	0.53 (0.17)	10

*Table 2.3 Pairwise comparisons of location error (distance in meters between estimated and known locations) between sites for slope trials, Boone County, Iowa, USA, 2017. Sites on the left of the table have greater (+), less (-), or equal (=) mean location error compared to sites along the top of the table. Site positions are illustrated in Figure 2.1. * indicates a significant difference using Tukey comparison at $\alpha = 0.05$.*

Site	1	2	3	4	5	6
1		_*	_*	_*	_*	_*
2	+*		=	=	_*	=
3	+*	=		=	_*	=
4	+*	=	=		_*	=
5	+*	+*	+*	+*		=
6	+*	=	=	=	=	

*Table 2.4 Pairwise comparisons of area (in ha) of 95% chi-square confidence ellipse between sites for slope trials, Boone County, Iowa, USA, 2017. Sites on the left of the table have larger (+), smaller (-), or equal (=) mean area compared to sites along the top of the table. Site positions are illustrated in Figure 2.1. * indicates significance using Tukey comparison at $\alpha = 0.05$.*

Site	1	2	3	4	5	6
1		=	=	_*	_*	_*
2	=		=	_*	=	_*
3	=	=		_*	_*	_*
4	+*	+*	+*		=	=
5	+*	=	+*	=		=
6	+*	+*	+*	=	=	

Figures

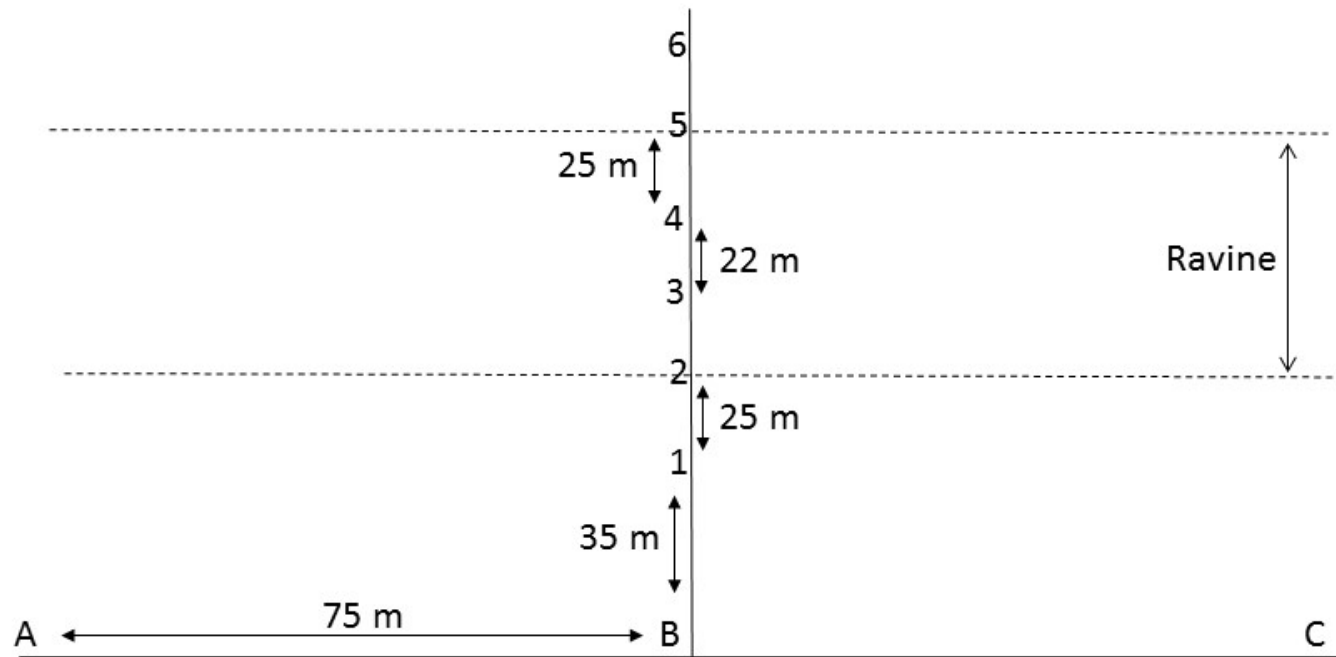


Figure 2.1 Locations of telemetry stations (A, B, C) and radio collar sites (1-6) for slope trials, Boone County, Iowa, USA, May-August 2017. A and B are located 75 m apart along a transect, as are B and C. Sequential radio collar sites are 25 m apart, except for sites 3 and 4, which are 22 m apart. Dashed lines indicate the lip of a ravine.

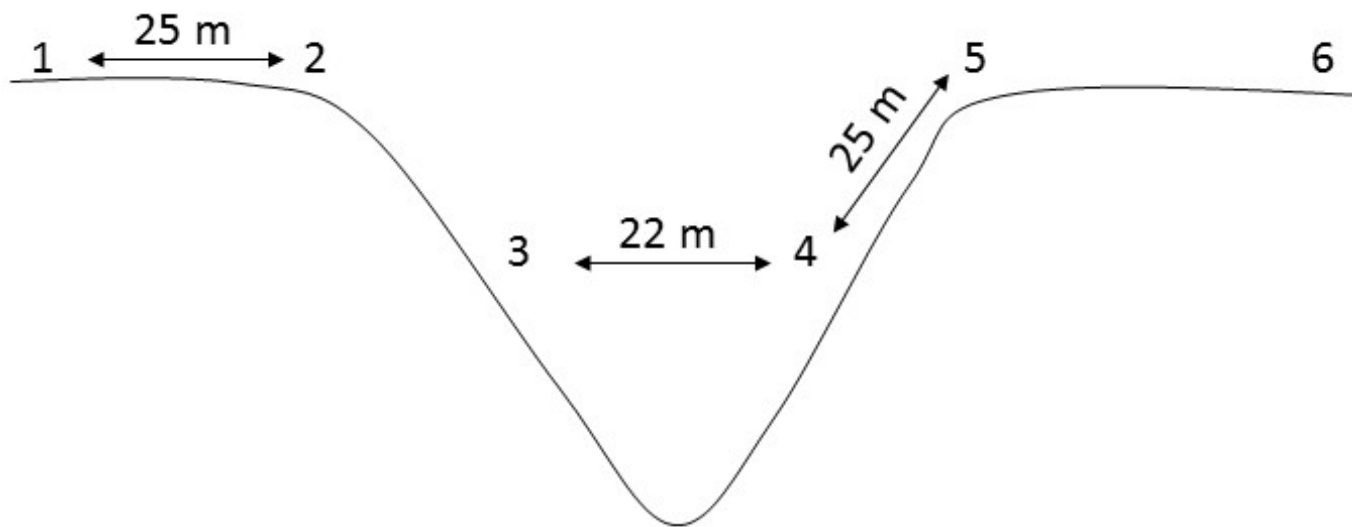


Figure 2.2 Locations of radio collar sites (1-6) relative to ravine topography for slope trials, Boone County, Iowa, USA, May-August 2017. Sequential sites are 25 m apart along a linear transect, except for sites 3 and 4, which are 22 m apart. Sites 1 and 6 are on level ground, sites 2 and 5 are at the lip of the ravine, and sites 3 and 4 are on the slope.

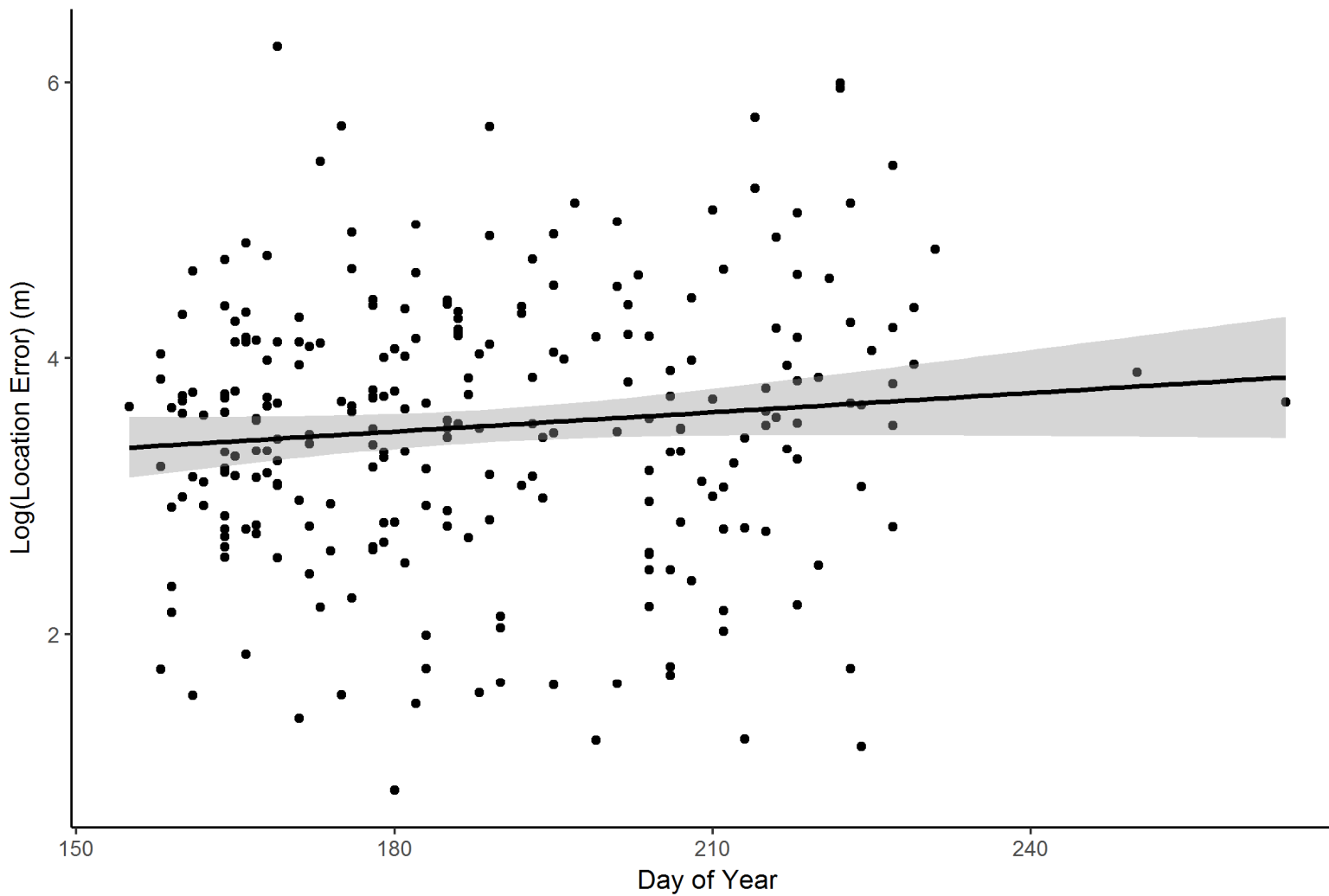


Figure 2.3 Linear regression modeling the relationship between day of year and log(location error) (m) for triangulation estimates of radio-collared white-tailed deer fawns, Boone County, Iowa, USA, May-August 2015-2017. Shaded area indicates 95% confidence intervals.

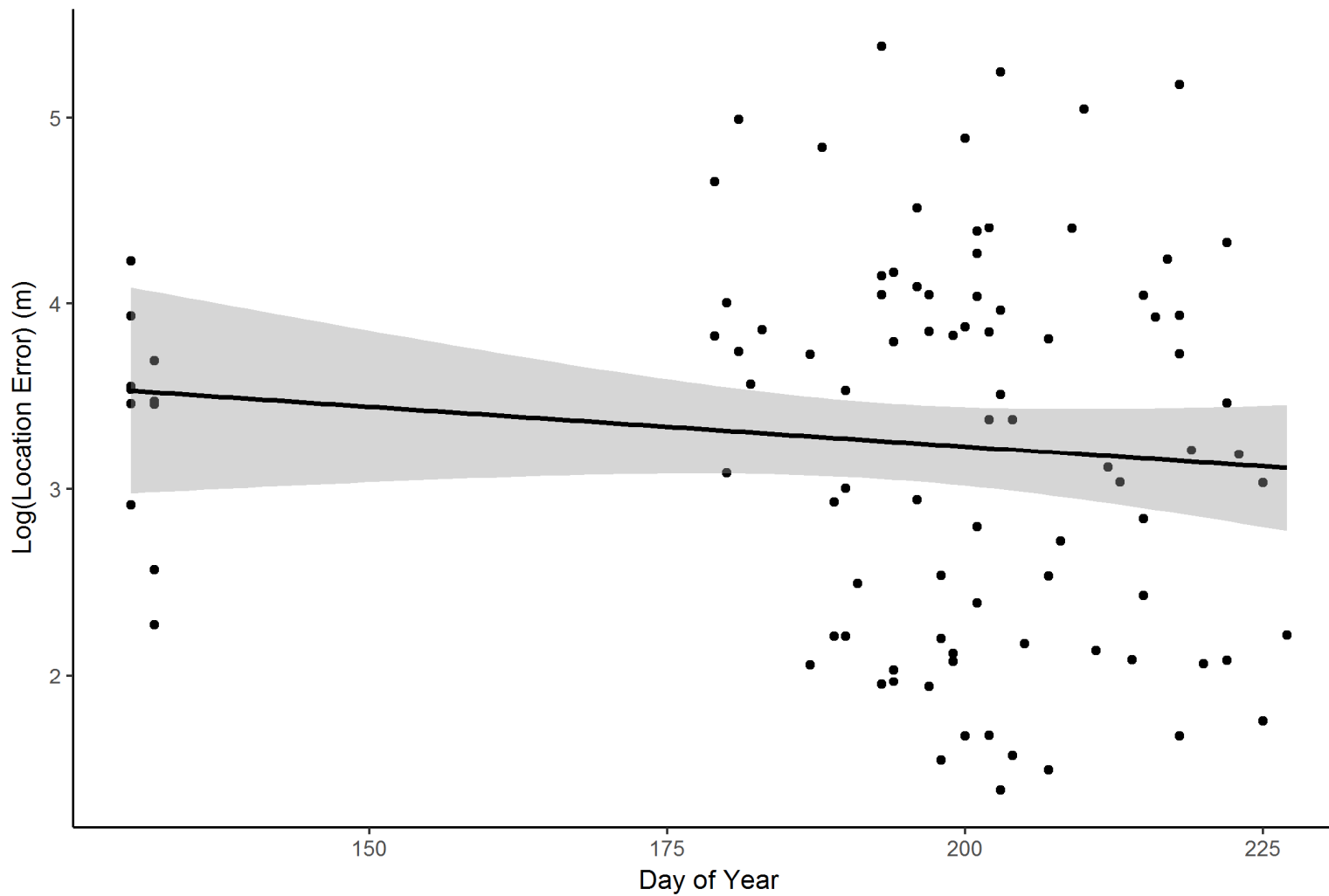


Figure 2.4 Linear regression modeling the relationship between day of year and log(location error) (m) for triangulation estimates of test collars by inexperienced observers, Boone County, Iowa, USA, May-August 2015-2017. Shaded area indicates 95% confidence intervals.

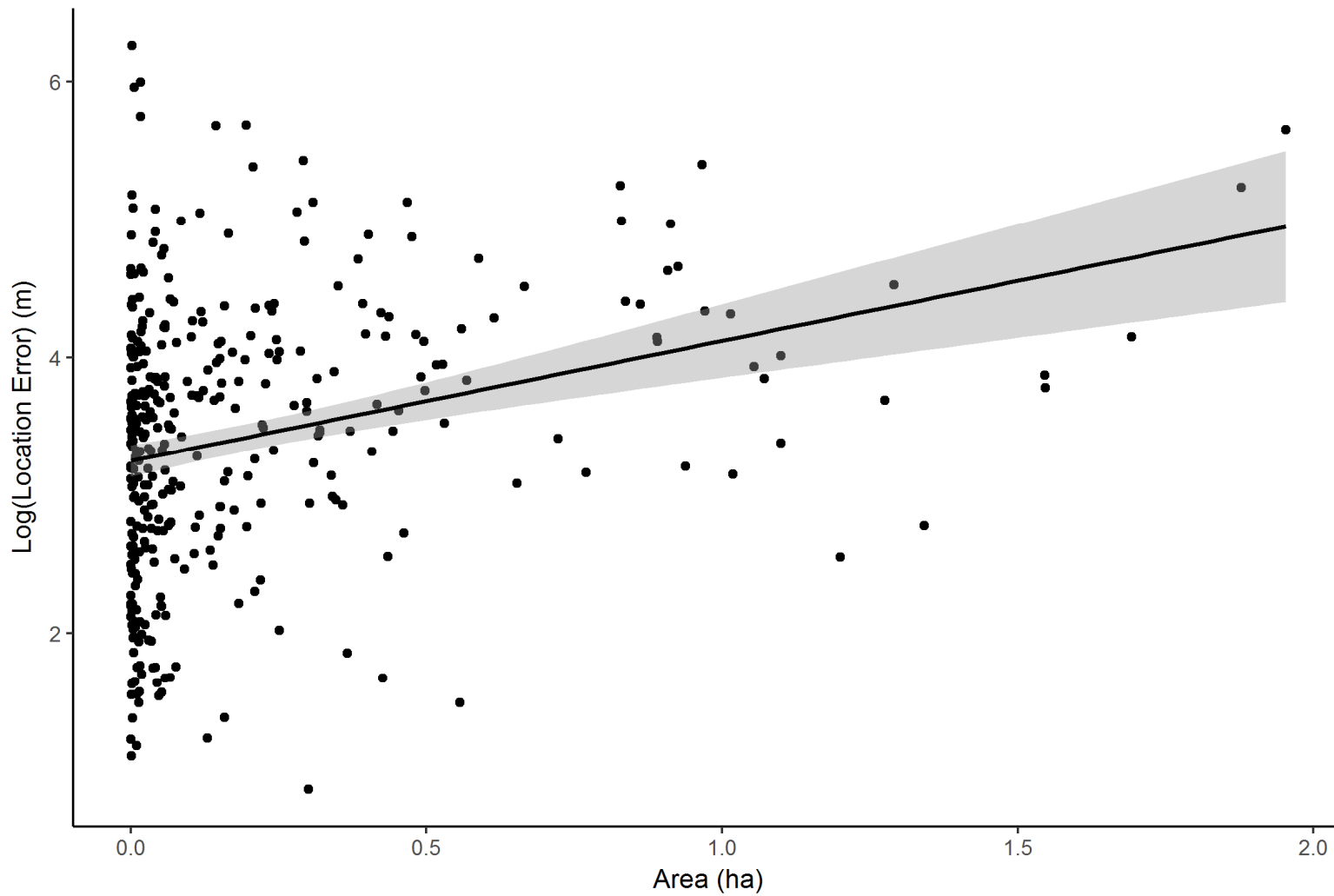


Figure 2.5 Linear regression modeling the relationship between area (ha) of 95% chi-square confidence ellipse and log(location error) (m) for triangulation estimates of test collars and radio-collared white-tailed deer fawns, Boone County, Iowa, USA, May-August 2015-2017. Shaded area indicates 95% confidence intervals.

GENERAL CONCLUSIONS

Summary

Our study provides survival estimates and descriptions of space use for white-tailed deer fawns in central Iowa. Fawn survival through 30 and 60 days post-capture was 0.78 (standard error = 0.06) and 0.69 (0.08) respectively. This is similar to estimates of 0.86 and 0.85 for the same intervals from a previous study in south-central Iowa (Huegel et al. 1985); however, our 7-month fawn survival estimate of 0.31 (0.02) was much lower than their 6-month estimate of 0.77. We attributed lower fawn survival through 7-months to mortality from disease and harvest. The primary sources of mortality in our study were disease, suspected predation, and harvest compared to mainly predation in other Midwestern fawn studies (Huegel et al. 1985, Rohm et al. 2007, Warbington et al. 2017). An outbreak of epizootic hemorrhagic disease (EHD) in 2016 caused 55% of our total disease mortality. The low predation mortality in our study may have been related to limited predator diversity and abundance, or to fawns selecting against low-cover agricultural habitat in favor of woodland, which had a positive effect on their survival rates. Similar results have been reported in other Midwestern studies (Rohm et al. 2007, Hiller et al. 2008). Our findings suggest that managers and private landowners interested in promoting fawn survival can plant or maintain woodland to provide fawns with sources of permanent cover in regions with limited or temporary cover like the agricultural Midwest. While EHD was responsible for many mortalities in a single year of our study, fawn survival was not significantly lower than other years.

We also evaluated the relationship between slope, fawn mobility, and observer experience and the accuracy of triangulation estimates. We found that distance between the

observer and radio telemetry transmitter explained our location error better than topography. By using signal strength as a measure of approximate distance to the transmitter, observers should reduce the distance at which they take triangulations to increase location accuracy. In our relatively simple study landscape, observer experience and fawn movement were not important factors in determining location accuracy. As long as triangulation remains a commonly used method of estimating animal locations (White and Garrott 1990), researchers need a way to validate the accuracy of their estimates efficiently (Saltz and White 1990). Our results indicate that using the confidence ellipse area as a proxy for location error is an acceptable method of validation in fawn telemetry studies.

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